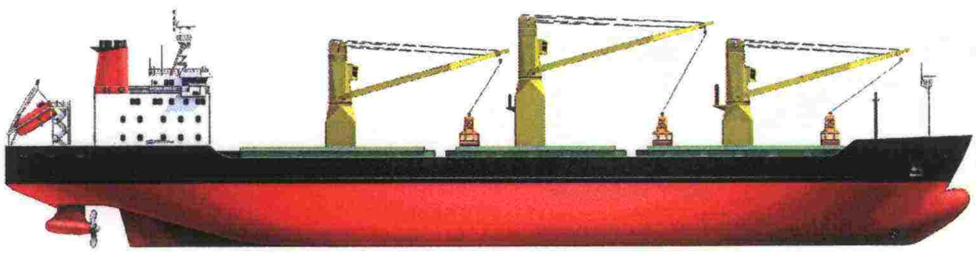
Merenkulkulaitoksen julkaisuja 7/2006

Study on frequent lines

Differences in running and investment costs between an icebreaking cargo vessel and a vessel that needs icebreaker assistance



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Abstract
The main objective of the study is to compare new icebreaking cargo ship solutions, mainly regarding winter shipping in ice conditions. The aim is to compare new ship solutions with standard type ice-class vessels in operation in the Northern Baltic and Gulf of Bothnia. The main focus will be on the determination of the need for icebreaking assistance for the cargo vessels. Three new ship designs will be created for Raahe-Luleå ore transportation. All the new designs have the same transport task and cargo-carrying capacity. Performance predictions both for icebreaking and open-sea sailing are made for the designs. The predictions are further used to determine the icebreaker assistance need. The first version is equipped with an extreme icebreaking bow form. The second version utilises the Double- acting icebreaking principle (azimuthing thruster and backwards icebreaking). The third version is a modification of the second version, where one azimuthing thruster is replaced with a Contra-Rotating Propulsion system.
Fuel consumption is calculated for each of the vessel alternatives. From fuel consumption, the environmental cost index will be determined and compared between the alternatives and the reference vessel. The reference vessel is a typical vessel used today in the traffic of Gulf of Bothnia.
For evaluating the need for icebreaker assistance, determining ice conditions are proposed for the Gulf of Bothnia. These ice conditions represent the typical worst conditions during a winter of normal ice conditions in the area.
Results of this study show that only extremely ice-capable vessels are able to operate in the area without icebreaker assistance. The Double-acting vessel type presented in this study was the only one to manage completely without icebreaker assistance. The calculated fuel and environmental cost indices for this vessel type are also the lowest. The investment cost for the vessel will be approximately 20% higher compared to a normal reference solution. Larger economic savings can be attained by new independently icebreaking cargo vessels, because the cost of icebreaker investment and operational costs can be saved. Therefore it is concluded that investing in the new cargo vessel is beneficial, and measures to support this investment for shipping operators should be made.

Keywords
Icebreaking, assistance, icebow, Double-acting, environmental cost index, fuel cost

Miscellaneous

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FOREWORD

The ice cover in the Bay of Bothnia annually causes major additional costs for the industry, ports, shipping companies as well as for the maritime administrations of Sweden and Finland. The costs growing most strongly are the fuel costs. During normal and severe winters the present icebreaker capacity is not sufficient to guarantee the required service level due to the increasing need for assistance in other sea areas. The industry and shipping companies must thus find other means in order to be able to ensure time-scheduled traffic.

The aim of this study is to present alternatives; how the ore transports between Luleå and Raahe could be made by four different I A Super ships, and how the costs would be divided in the different alternatives.

The study also provides grounds for evaluating the economic measures to be taken in order to secure year-round traffic in the Bay of Bothnia both from the point of view of national economy and in a way that satisfies the companies in the field.

The study is part of the EU's TEN project Master Plan Studies for Development of the Motorways of the Baltic Sea. The preparation of the study has been led by Director Ilmari Aro and project manager Emmi Saarinen from the Winter Navigation Department of the Finnish Maritime Administration, and by the international members of Baltic Icebreaking Management (BIM). The authors of the study are Reko-Antti Suojanen, Pekka Salmi and Esa Hakanen from Aker Arctic Technology Ltd (AARC).

Helsinki, November 10, 2006

Ilmari Aro
Chairman of Baltic Icebreaking Management

TABLE OF CONTENTS

1 Introduction

The main objective of the study is to compare new icebreaking cargo ship solutions mainly regarding winter shipping in ice conditions. The aim is to compare new ship solutions with standard type ice-class vessels in operation in the Northern Baltic and the Gulf of Bothnia. The route looked at in this study is between the ports of Raahe and Luleå. This route has difficult ice conditions and a long ice period. Today's transport services are provided with pusher–barge combinations and icebreaker assistance provided by the Finnish and Swedish Maritime Administrations.

This study has been done to compare the present shipping system with new- technology ship concept solutions that should be capable of navigation mostly or completely without icebreaker assistance. With these solutions, both the overall economics and the environmental impact might be more favourable.

The work has been done by designing three different ship alternatives for the route and comparing their navigation capability to a reference vessel of conventional design. The costs of these different ship concepts can be compared. The environmental comparison has been done by considering machinery emissions from the ships and assisting icebreakers. The ship operational profiles will be created on the basis of constant shipment volumes and typical winter ice conditions on the particular route. The ship fuel consumption in ice conditions will be estimated using an icebreaking simulation programme. The estimates of the use of icebreakers are based on long operational experience of the Finnish and Swedish Maritime Administrations in the shipping area under consideration.

2 Ship designs

For this study four different concept-level ship designs have been created. The vessels will have common main design criteria and cargo-carrying capability in order to make the vessels comparable for purposes of the study. The vessels are designed for the Raahe-Luleå route and all of them have a minimum of IA Super Finnish Swedish ice class. The vessels are designed for carrying ore cargo of about 16,000 tonnes. All vessels are designed to have a minimum of 15 knots open water service speed. The maximum draft for the vessels is 9.0 metres. The vessels are designed to be as self-operable as is practically possible in the ice conditions of the Gulf of Bothnia. The design criterion is to minimise the need of icebreaker assistance in the operation.

The three new vessel designs are compared to a reference vessel, which is a typical standard IA Super ice-class vessel (called version 0).

The following table summarises the concept designs and, in later chapters, the vessels are presented in more detail.

Table 1 Main design criteria

MAIN DESIGN CRITERIA		
Cargo capacity, dwt	16,000	Tonnes
Vessel draft	9.0	Metres
Service speed	15.0	Knots
Ice class	IA Super	
NRT	5,400	Tonnes

Table 2 Main dimensions of the ship concepts

SHIP CONCEPTS	Loa	Bwl	T	DWT	Hull type Machinery	Propeller
	(m)	(m)	(m)	(tonnes)		
Version A	153.4	23	9	16,000	Icebow Slow speed	1 controllable pitch
Version B	151.3	23	9	16,000	Bulb bow 3 medium speed Diesel-el	Azipod with fixed pitch propeller
Version C	151.3	23	9	16,000	Bulb bow Slow speed Diesel-el	Azipod + controllable propeller on shaft
Version 0 (reference)	145.9	23	9	16,000	Bulb bow Slow speed	1 controllable pitch

Performance prediction methods

The open water speed-power prediction is made on the basis of Holtrop method /1/. In the prediction, the still water speed is calculated as a function of the propulsion power (kW). In addition, a 15% sea margin is used for dimensioning the propulsion motors. The sea margin is used to overcome the wave and wind effects, the aging of the propulsion machinery and the fouling of the ship hull. With a 15% sea margin, the service speed of the vessel can be guaranteed during the practical life time of the vessel.

Icebreaking predictions for the vessels A and O are based on methods developed by Linqvist /3/. The formulae presented by this method are further verified and modified based on the AARC model and full-scale test results.

The astern icebreaking prediction (versions B and C) is based on references to the results of similar types of icebreaking vessels in model and full-scale tests.

In the prediction, the speed of the vessel is shown in unbroken level ice. This speed will be achieved with full available propulsion power (about 85% MCR).

2.1 IA Super ice class ship with shaft line propulsion

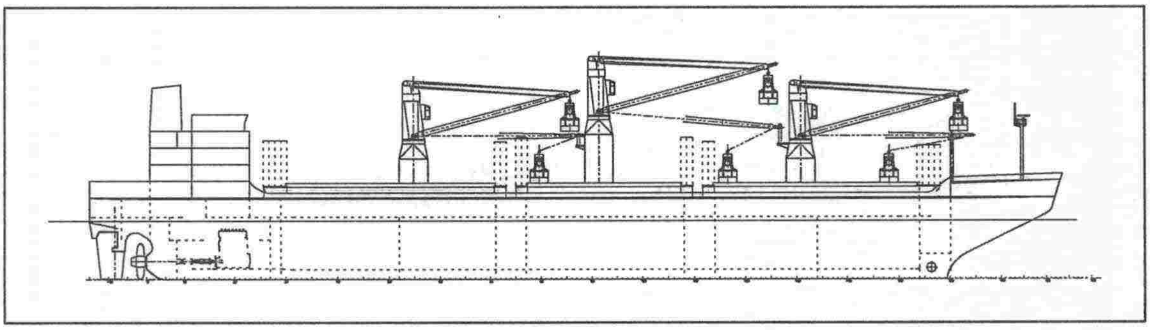

Figure 1 Side view of version A design. General arrangement drawing is shown in Appendix A.

2.1.1 Short outline specification

The 16,000 dwt ice-going bulker is about 150 m long, has a capacity of 16,000 tonnes, is very ice-capable, and is primarily intended to carry bulk cargoes in the northern Baltic Sea and the Gulf of Bothnia. The ice navigation and icebreaking capability is so good that the vessel is generally able to operate independently in almost all expected ice conditions throughout the winter, so, by and large, it does not need icebreaker assistance.

The actual operation and cargo have not yet been defined, and consequently the winter time transport of iron ore from Luleå to Raahe has been proposed, as has the transport of limestone and coal in the Baltic. During the winter, the vessel may be tied to a certain route in Bothnian ice navigation, but during the summer, it is in principle free to operate worldwide. Because of this, much lighter cargoes than ore may also be carried.

Icebreaking and ice operation capability is very good, so the vessel is able to proceed effectively in most expected ice conditions, and also to prepare a broken channel of reasonable quality for vessels that may be following it. Other ways or methods of assisting other vessels have not been studied. The 'traditional version' is traditional in that the vessel operates icebow ahead. Consequently, what is not traditional is that it is provided with a highly efficient icebreaking bow rendering its icebreaking capability very good. Otherwise the hull form is of the traditional type for a normal cargo vessel.

The vessel is provided with a single deck and double hull, forecastle and poop deck, cargo holds in midships, superstructure for accommodation and engine room aft.

Cargo holds are provided with smooth inner bulkheads, tank top strengthened for heavy cargoes and cargo handling with grabs, and hydraulically operated folding full width hatch covers. For independent self-sustained cargo handling, there are three large deck cranes on the port side, provided with grabs.

The ice class is IA Super, applied according to the expected ice conditions and the proposed method of operation. Therefore strengthening the hull and propulsion can exceed the class requirements.

Main Dimensions

Length oa	153	m
Length dwl	148	m
Beam	23	m
Draught	9	m
Depth	12.4	m

Capacities

Deadweight at 9 m draught is 16,000 tonnes, of which 15,000 tonnes can be considered as cargo. The 1,000-tonne reservation for ship stores means a substantially long range.

Cargo holds

There are three cargo holds, with a width of about 18.4 m and a depth of about 12.7 m. Capacities:

Hold 1	7,250 m^3
Hold 2	5,800 m^3
Hold 3	7,650 m^3
Total	20,700 m^3

With this hold capacity, the cargo deadweight will be utilised when the specific gravity of cargo exceeds 0.72. Heavier cargoes, such as iron ore, need only a fraction of the hold volumes.

Fuel capacity

The two large fuel oil tanks in the general arrangement sketch have a capacity of about 1,400 m^3. With full tanks, the vessel is able to cruise for over 15,000 miles at a speed of 14 knots. The fuel tanks are not located adjacent to the sea. For extra tankage for fuel or other purposes, there is plenty of room if required.

There is an abundance of ballast tanks in the double hull and double bottom, over 9,000 m^3 in all. There is adequate ballast capacity, especially in the bow, to prevent excessive aft trim in ballast condition.

Accommodation

Accommodation is provided for a crew of about 15 according to cargo vessel standards. In addition, a cabin or two are provided for supernumeraries. For the crew, repairmen and visitors, single- and double-occupancy cabins with toilet/shower modules are provided, and suites with day room, bed room and toilet/shower for the officers.

Mess rooms, day rooms, offices, service and work spaces have been fitted according to cargo vessel standards.

Performance

The MCR rating of the main engine is 8,280 kW. A 15 knots service speed is achieved at about 7,000 kW, the main engine running at about 85 % power. Full-power trial speed is over 16 knots.

At full power the bollard pull force is about 110 tonnes.

In ice conditions, the vessel operates using the traditional method, always bow ahead. Reversing in ice conditions is restricted as for any normal cargo vessel.

In level ice of 1.0 m thickness, the vessel is able to achieve 4 knots constant speed, and, theoretically, 1.5 m-thick level ice can be broken. In a 'class rule ice channel' for IA Super ice class of 1.0 m thickness, over 12 knots speed can be achieved.

Steering capability in ice conditions is limited as in any traditional type vessel. In easy ice conditions and in open water at low speed, the turning capability can be improved using bow and stern thrusters.

Reversing capability is 'traditional'. In open water, reversing is difficult to control, and, in ice conditions, reversing must be done with care and the rudder in the central position. The low reverse thrust of the cp-propeller may make it difficult to extract the vessel if it gets stuck when ramming.

Machinery

The propulsion machinery is traditional. The 5.5 m-diameter cp-propeller is driven by a direct-coupled slow-speed diesel engine, of about 8,280 kW power.
Three auxiliary diesel generators are installed, about 1,080 kW each, and an emergency generator of about 110 kW.

There is also an oil-fired steam boiler of about 2.5 t/h, and an exhaust gas economiser of about 1.1 t/h.

The rudder is of the balanced horn type, provided with a hydraulic steering gear. In addition bow and stern thrusters of about 650 kW power are provided.

Fuel is heavy fuel oil. The fuel consumption of the main engine is in the 30 tonnes/day range at the service speed, according to the configuration of the machinery and types of engines.

In addition to the heavy fuel system, a diesel oil system is also installed for diesel oil consumers and as a spare for the fuel oil system.

The cooling system for the machinery is designed to ensure that the full power of the machinery is available at slow speeds in ice conditions.

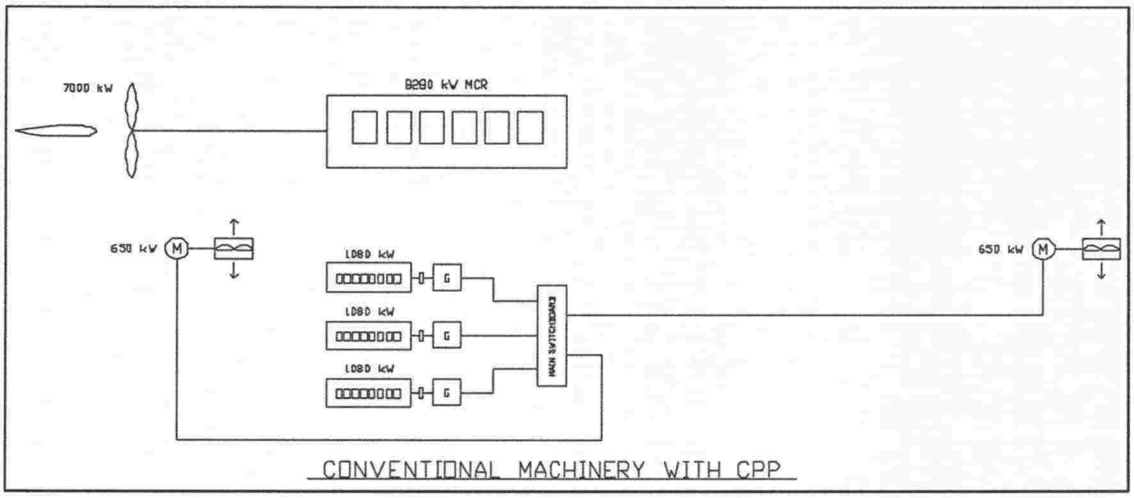

Figure 2 Machinery diagram

Steel structure

The vessel has a double hull, both double bottom and double sides. The sides are preferably transversally framed, the bottom, tank top, inner sides and deck may be longitudinally stiffened. High-strength steel may be used in areas, which are heavily exposed to ice loads, where the most benefit can be drawn. In the cargo holds, the tank top and the bulkheads are strengthened for heavy cargoes and the use of grabs.

Ice strengthening is done according to a minimum of IA Super standard, taking into account that the bulker is intended to navigate independently in ice conditions. This means that it will meet and break the ice itself, whereas a normal IA Super class vessel meets a channel that has already been broken by an icebreaker. Capability to withstand ice compression is checked, especially for the midships section. The magnitude of ice strengthening might be increased in the bow for ramming in high ice formations, and longitudinal strength reflects a light ramming capability.

The underwater shell will be painted with wear-resistant epoxy based Inerta-160 paint for increasing the life time of the paint, and to reduce added ice resistance that might be caused by increasing the roughness of the shell.

Outfit

Deck cranes, 3 pcs., are of 25 tonnes/25 m outreach capacity, and grabs about 10 m^3. Small hydraulic telescopic knuckle boom cranes are installed on both sides as store/service cranes.

Cargo hatch covers are of the same width as the cargo holds, and have hydraulically operated folding panels. For emptying and cleaning the holds, a wheel loader is delivered, provided with suitable lifting points and equipment.

Life-saving equipment consists of a free-fall lifeboat, life-rafts, floating apparatus in accordance with regulations, emergency suits, etc. In addition, a small work boat is installed.

2.1.2 Speed power prediction

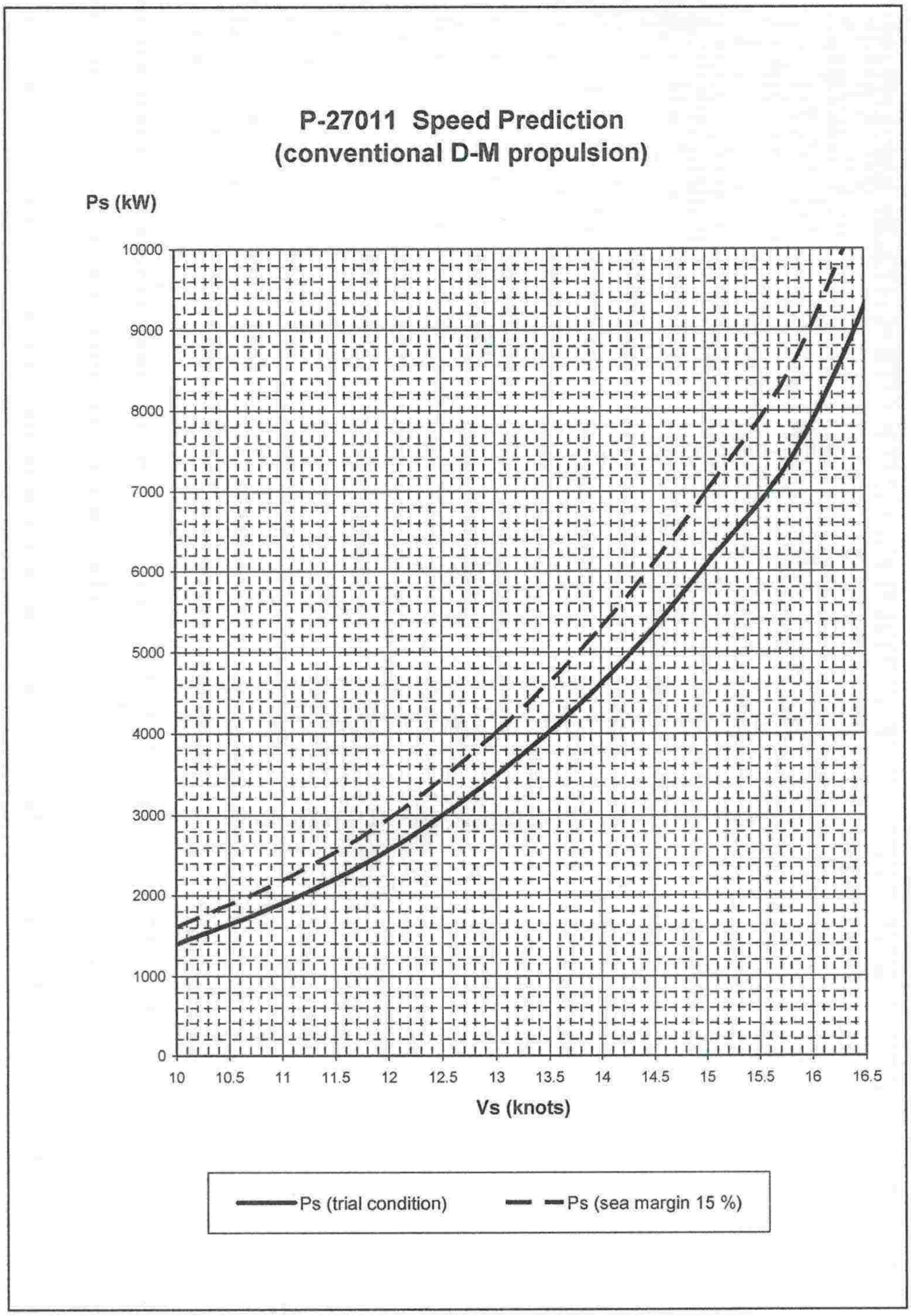

Figure 3 Speed prediction for the version A ship.

The propulsion power (kW) is calculated as a function of the ship speed (knots). The lower curve shows a trial prediction in still water. The upper dotted curve shows the power requirement with a 15% sea margin added to the trial prediction.

2.1.3 Icebreaking prediction in level ice

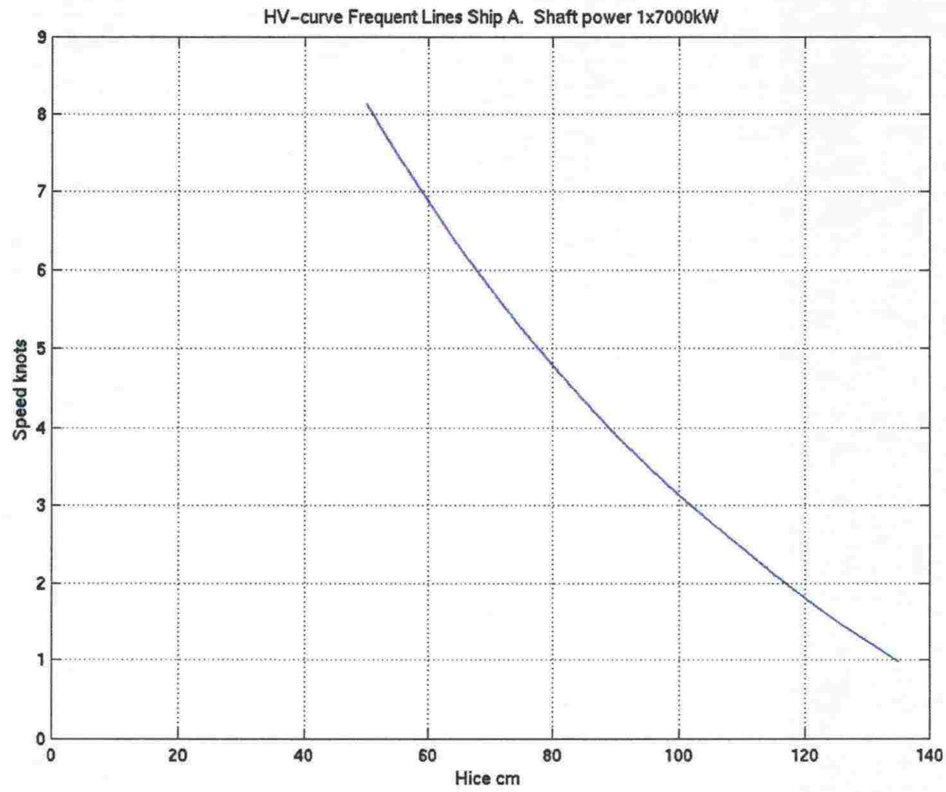

Figure 4 Speed – ice thickness (HV) plot for traditional ship

In the prediction, the speed at the vessel's full operational power is shown in different unbroken level ice thicknesses. The A version is able to break up to 135 cm of ice at a speed of one knot. At a speed of 5 knots, it can break about 75 cm of ice.

2.2 Icebreaking Double-acting type vessel for IA Super ice class

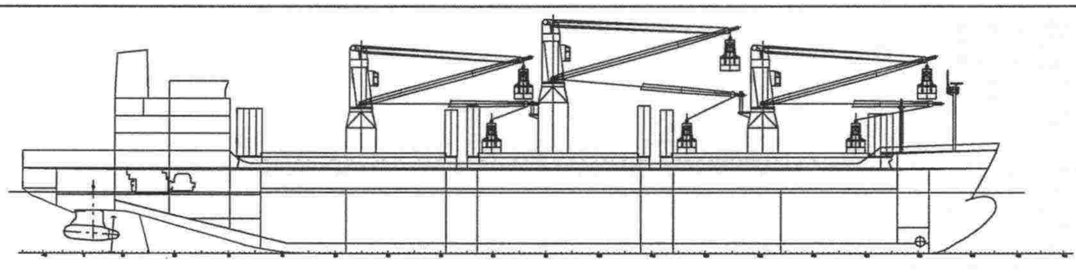

Figure 5 Side view of version B design. General arrangement drawing is shown in Appendix A.

2.2.1 Short outline specification

The 16,000 dwt bulker/icebreaker is about 150 m long, has a capacity of 16,000 tonnes, is a very ice-capable double-acting bulk carrier, and is primarily intended to carry bulk cargoes in the northern Baltic Sea and the Gulf of Bothnia. The ice navigation and icebreaking capability is so good that the vessel is able to operate independently in all expected ice conditions throughout the winter, without the need for icebreaker assistance. It is in principle able to provide assistance to other vessels operating in the area, which are able to follow in the channel that it breaks. Other types of assistance are not possible or permitted.

The actual operation and cargo have not yet been defined, and, consequently, wintertime transport of iron ore from Luleå to Raahe is proposed, as is the transport of limestone and coal in the Baltic. During the winter, the vessel may be tied to a certain route or area because of her usefulness in ice navigation, but during the summer, it is in principle free to go worldwide. Because of this, much lighter cargoes may also be carried.

Icebreaking and ice operation capability is excellent, so the vessel is able to proceed effectively in all expected ice conditions and to prepare a broken channel of reasonable quality for the other vessels to follow. (As a reference, the MS Norilsky Nickel vessel with similar main dimensions and the same operating principle was able to break 1.5 m ice at a speed of 3.5 knots at 13 mw shaft power /2/). According to the double acting principle, it operates astern when ice conditions are difficult, but in light ice conditions, such as in channels and in open water, it proceeds ahead. For the efficiency of open water operation, the bow is of bulbous form. In addition to breaking the ice and preparing a channel for the other vessels, it is not expected to perform other types of assistance.

The vessel is provided with a single deck and double hull, forecastle and poop deck, cargo holds in midship, superstructure for accommodation and engine room aft. Cargo holds are provided with smooth inner bulkheads, tank top strengthened for heavy cargoes and cargo handling with grabs, and hydraulically operated folding full width hatch covers. For independent self-sustained cargo handling, there are three large deck cranes on the port side, provided with grabs.

The ice class is a minimum of IA Super, applied according to the expected ice conditions and the proposed method of operation. Therefore the ice strengthening of the hull and propulsion system exceeds IA Super class requirements.

Main Dimensions

Length oa	149	m
Length dwl	144	m
Beam	23	m
Draught	9	m
Depth	12.4	m

Capacities

Deadweight at 9 m draught is 16,000 tonnes, of which 15,000 tonnes can be considered as cargo. The 1,000 tonne reservation for ship stores means a substantially long range.

Cargo holds

There are three cargo holds, with a width of about 18.4 m and a depth of about 12.7 m. Capacities:

Hold 1	7,700 m^3
Hold 2	5,800 m^3
Hold 3	6,500 m^3
Total	20,000 m^3

With this hold capacity, the cargo deadweight will be utilised when the specific gravity of cargo exceeds 0.75. Heavier cargoes, such as iron ore, need only a fraction of the hold volumes.

Fuel capacity:

The two large fuel oil tanks in the general arrangement sketch have a capacity of about 1,400 m³. With full tanks, the vessel is able to cruise for over 15,000 miles at a speed of 14 knots.

The fuel tanks are not located adjacent to the sea.

For extra tankage for fuel or other purposes, there is plenty of room if required. There is an abundance of ballast tanks in the double hull and double bottom, over 9,000 m³ in all. The full bulbous bow and buttock flow stern allow for extra buoyancy, so that the double-acting version is shorter than the other two contenders, and tends to float closer to even keel. Consequently, more ballast capacity may be needed aft for providing adequate immersion for the propeller in ballast condition.

Accommodation

Accommodation is provided for a crew of about 15, according to cargo vessel standards. In addition, a cabin or two are provided for supernumeraries. For the crew, repairmen and visitors, single- and double-occupancy cabins with toilet/shower modules are provided, and suites with day room, bed room and toilet/shower for the officers.

Mess rooms, day rooms, offices, service and work spaces have been fitted according to cargo vessel standards.

Performance

The shaft power of the Azipod propulsion device is 7,600 kW. 15 knots service speed is achieved at about 7,600 kW, the main engine running at about 80 % power. Full-power trial speed is over 15.5 knots.
At full power, the bollard pull force is about 100 tonnes ahead and 87 tonnes astern.

In ice conditions, the double-acting version normally operates astern. In astern mode, 1 m-thick level ice can be broken at a speed of 4 knots. In a 'class rule channel' for IA Super class of 1 m thickness, over 12 knots speed can be achieved. In astern mode, even the most difficult ice ridges and other difficult ice conditions can be penetrated efficiently.

Steering capability is excellent both ahead and astern, both in open water and in ice conditions. Due to the good steering and manoeuvring capability, the vessel is well suited to Arctic navigation where good turning ability is needed in tactical navigation.

Machinery

The propulsion machinery consists of one Azipod of 7,600 kW power, and three main diesel generators of about 11,000 kW total power. The main generators feed the 6.3 kV propulsion network, which in turn feeds the Azipod propulsion motor via a frequency converter, and the ship service network via transformers. In addition, a harbour diesel generator and emergency diesel generator are installed.

There is also an oil-fired steam boiler of about 2.5 t/h, and exhaust gas economisers for the main engines of about 1.1 t/h, according to the type of main engines installed.

Steering is by the Azipod, which is turned by a hydraulic turning system. In addition, a bow thruster of about 650 kW power is provided.
Fuel is heavy fuel oil. The fuel consumption is in the 35 - 40 tonnes/day range at the service speed.

In addition to the heavy fuel system, a diesel oil system is also installed for diesel oil consumers and as a spare for the fuel oil system.

The cooling system for the machinery is designed to ensure that the full power of the machinery is available at slow speeds in all ice conditions.

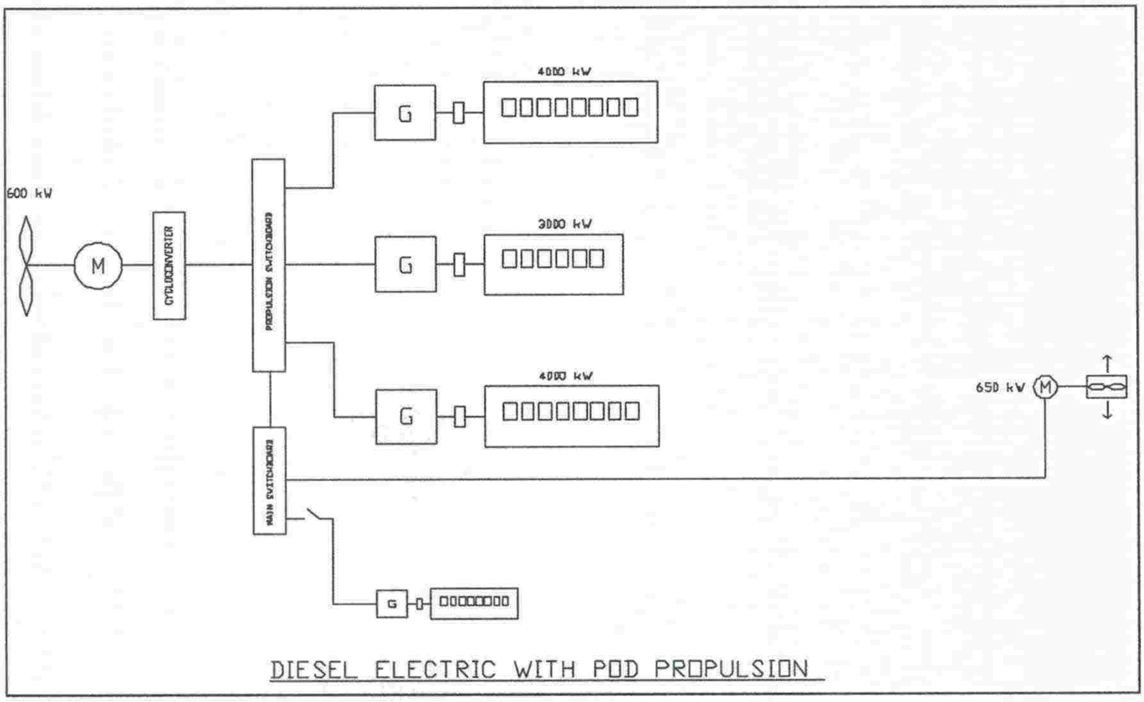

Figure 6 Machinery diagram

Steel structure

The vessel has a double hull, both double bottom and double sides. The sides are preferably transversally framed, the bottom, tank top, inner sides and deck may be longitudinally stiffened. High-strength steel may be used in areas, which are heavily exposed to ice loads, where the most benefit can be drawn. In the cargo holds, the tank top and the bulkheads are strengthened for heavy cargoes and the use of grabs.

Ice strengthening is done according to a minimum of IA Super standard, taking into account the double-acting method and independent operation in ice conditions. This means that the vessel will meet and break the ice itself, whereas the 'normal' IA Super class vessel meets ice in a channel that has already been broken by an icebreaker. Capability to withstand ice compression is checked especially for the midship, and the magnitude of ice strengthening might be increased in the stern for operation in high ice formations.

The underwater shell will be painted with wear-resistant epoxy based Inerta-160 paint for increasing the life time of the paint, and to reduce the added ice resistance that might be caused by increasing the roughness of the shell.

Outfit

Deck cranes,3 pieces, are of 25 tonnes/25 m outreach capacity, and grabs about 10 m^3. Small hydraulic telescopic knuckle boom cranes are installed on both sides as store/service cranes.

Cargo hatch covers are of the same width as the cargo holds, which have hydraulically operated folding panels. For emptying and cleaning the holds, a wheel loader is delivered, provided with suitable lifting points and equipment.

Life-saving equipment consists of a free-fall lifeboat, life-rafts, floating apparatus in accordance with regulations, emergency suits, etc. In addition, a small work boat is installed.

2.2.2 Speed power prediction

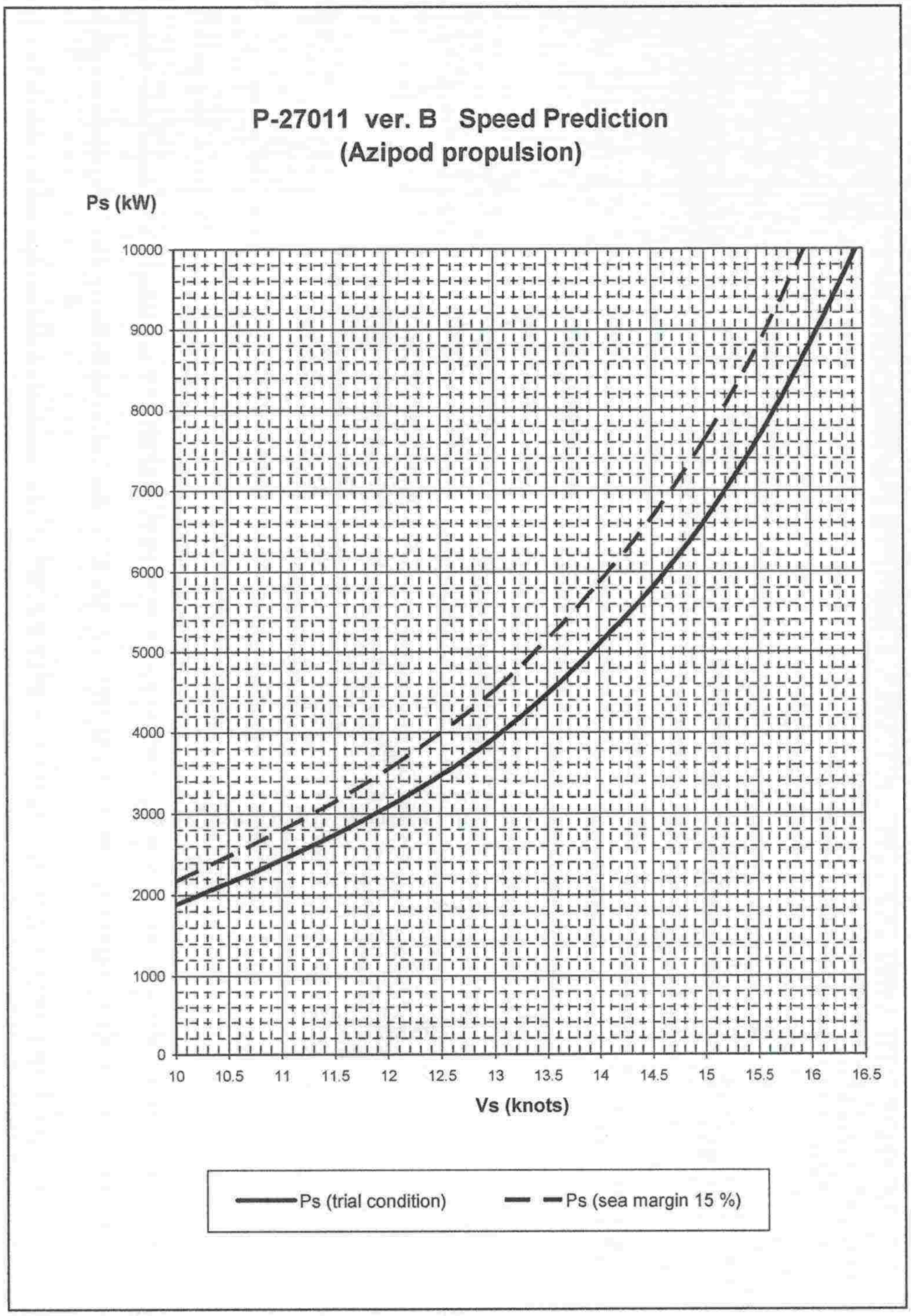

Figure 7 The propulsion power (kW) is calculated as a function of the ship speed (knots). The lower curve shows a trial prediction in still-water calm conditions. The upper dotted curve shows the power requirement with a 15% sea margin added to the trial prediction.

2.2.3 Ice breaking prediction

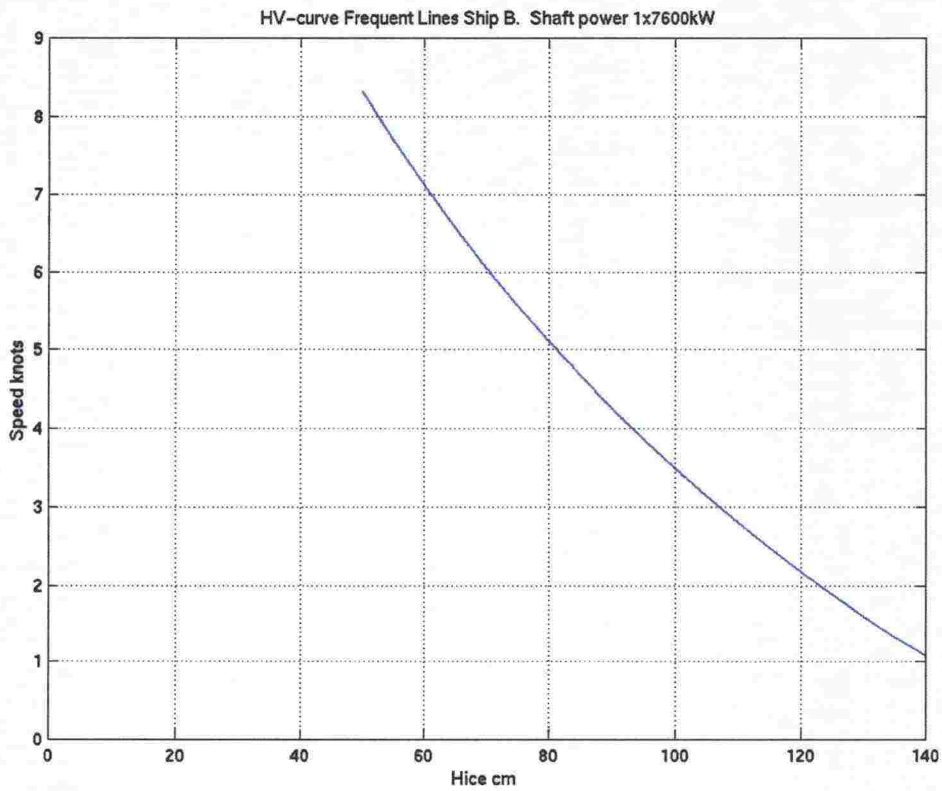

Figure 8 Speed – ice thickness (HV) plot for Double-acting ship (astern)

In the prediction, the speed at the vessel's full operational power is shown for different unbroken level ice thicknesses. The B version is able to break up to 140 cm of ice at a speed of one knot. At a speed of 5 knots, it can break about 80 cm of ice.

2.3 Double-acting type vessel with CRP propulsion

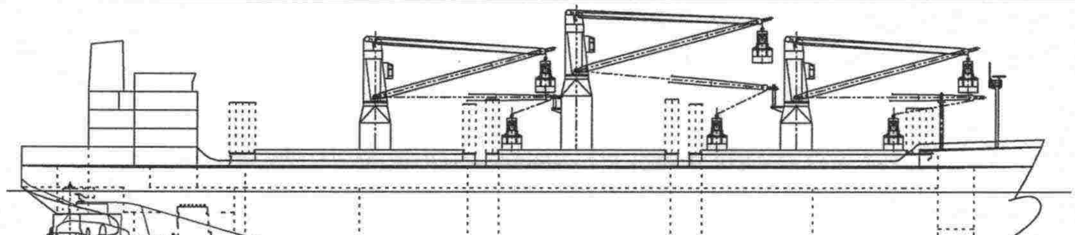

Figure 9 Side view of version C design. General arrangement drawing is shown in Appendix A.

The 16,000 dwt bulker/icebreaker is about 150 m long, has a 16,000-tonne capacity, is a very ice-capable double-acting bulk carrier, and is primarily intended to carry bulk cargoes in the northern Baltic Sea and the Gulf of Bothnia. The ice navigation and icebreaking capability is so good that the vessel is able to operate independently in all expected ice conditions throughout the winter, so does not need icebreaker assistance. It is in principle able to provide assistance for other vessels operating in the area, which are able to follow in the channel it has broken. Other types of assistance with towing are not possible.

The actual operation and cargo have not yet been defined, and, consequently, wintertime transport of iron ore from Luleå to Raahe is proposed, as is the transport of limestone and coal in the Baltic. During the winter, the vessel may be tied to a certain route or area because of her usefulness in ice navigation, but during the summer, it is in principle free to go worldwide. Because of this, much lighter cargoes may also be carried.

Icebreaking and ice operation capability are good, so the vessel is able to proceed effectively in most expected ice conditions and to prepare a broken channel of reasonable quality for vessels following it. According to the double- acting principle, it operates astern when ice conditions are difficult, but in light ice conditions, such as in channels and in open water, it proceeds ahead.

For the efficiency of open water operation, the bow is of a bulbous form. Furthermore, the efficiency of the propulsion is improved using contra-rotating propulsion with a mechanically driven main propeller, and a contra-rotating Azipod propeller behind the main propeller.

The vessel is provided with a single deck and double hull, forecastle and poop deck, cargo holds in midship, superstructure for accommodation and engine room aft. Cargo holds are provided with smooth inner bulkheads, the tank top is strengthened for heavy cargoes and cargo handling with grabs, and there are hydraulically operated folding full width hatch covers. For independent self-sustained cargo handling, there are three large deck cranes on the port side, provided with grabs.

The ice class is a minimum of IA Super, applied according to the expected ice conditions and the proposed method of operation. Therefore the ice strengthening of the hull and propulsion system exceeds IA Super class requirements.

Main Dimensions

Length oa	147 m
Length dwl	144 m
Beam	23 m
Draught	9 m
Depth	12.4 m

Capacities

Deadweight at 9 m draught is 16,000 tonnes, of which 15,000 tonnes can be considered as cargo. The 1,000 tonne reservation for ship stores means a substantially long range.

Cargo holds
There are three cargo holds, with a width of about 18.4 m and a depth of about 12.7 m. Capacities:

Hold 1	7,700 m^3
Hold 2	5,800 m^3
Hold 3	7,400 m^3
Total	20,900 m^3

With this hold capacity, the cargo deadweight will be utilised when the specific gravity of cargo exceeds 0.72. Heavier cargoes, such as iron ore, need only a fraction of the hold volumes.

Fuel capacity

The two large fuel oil tanks in the general arrangement sketch have a capacity of about 1,400 m^3. With full tanks, the vessel is able to cruise for over 15,000 miles at a speed of 14 knots.

The fuel tanks are not located adjacent to the sea.

For extra tankage for fuel or other purposes, there is plenty of room if required. There is an abundance of ballast tanks in the double hull and double bottom, over 9,000 m^3 in all.

Accommodation

Accommodation is provided for a crew of about 15, according to cargo vessel standards. In addition, a cabin or two are provided for supernumeraries. For the crew, repairmen and visitors, single- and double-occupancy cabins with toilet/shower modules are provided, and suites with day room, bed room and toilet/shower for the officers.

Mess rooms, day rooms, offices, service and work spaces are fitted according to cargo vessel standards.

Performance

Total shaft power is 7,600 kW, of which the main propeller is 4,300 kW and Azipod 3300 kW. 15 knots service speed is achieved at about 7,150 kW, the main engine running at about 89 % power. Full-power trial speed is over 16 knots.

At full power the bollard pull force is about 64 tonnes astern.
In ice conditions, the double-acting version operates normally astern. In astern mode, 1 m-thick level ice can be broken at a speed of 2 knots, and, theoretically, up to 1.2 m-thick level ice can be broken. In a 'class rule channel' for IA Super class of 1 m thickness, over 10 knots speed can be achieved. In astern mode, even the most difficult ice ridges and other difficult ice conditions can be penetrated efficiently.

Steering capability is good in both ahead and astern operation in ice, due to the steering force of the Azipod. Due to the good steering and manoeuvring capability, ice navigation is effective. Steering capability in open water is also expected to be good, but the course-keeping capability in open water especially needs to be checked in the more detailed development of the CRP system.

Machinery

Propulsion machinery consists of one slow-speed diesel engine of 4,320 kW power, driving a directly coupled cp-propeller, and a 3,300 kW Azipod installed behind the main propeller. The Azipod is powered by two diesel generators, of 2,700 kW power each, which also feed the ship service power network. In addition, a harbour diesel generator and emergency diesel generator are installed.

There is an oil-fired steam boiler of about 2.5 t/h, and exhaust gas economisers for the main engines of about 1.1 t/h, according to the type of main engines.
Steering is by the Azipod, which is turned hydraulically. In addition, a bow thruster of about 650 kW power is provided.

Fuel is heavy fuel oil. The fuel consumption is in the 30 tonnes/day range at the service speed.

In addition to the heavy fuel system, a diesel oil system is also installed for diesel oil consumers and as a spare for the fuel oil system.

The cooling system for the machinery is designed to ensure that the full power of the machinery is available at slow speeds in ice conditions.

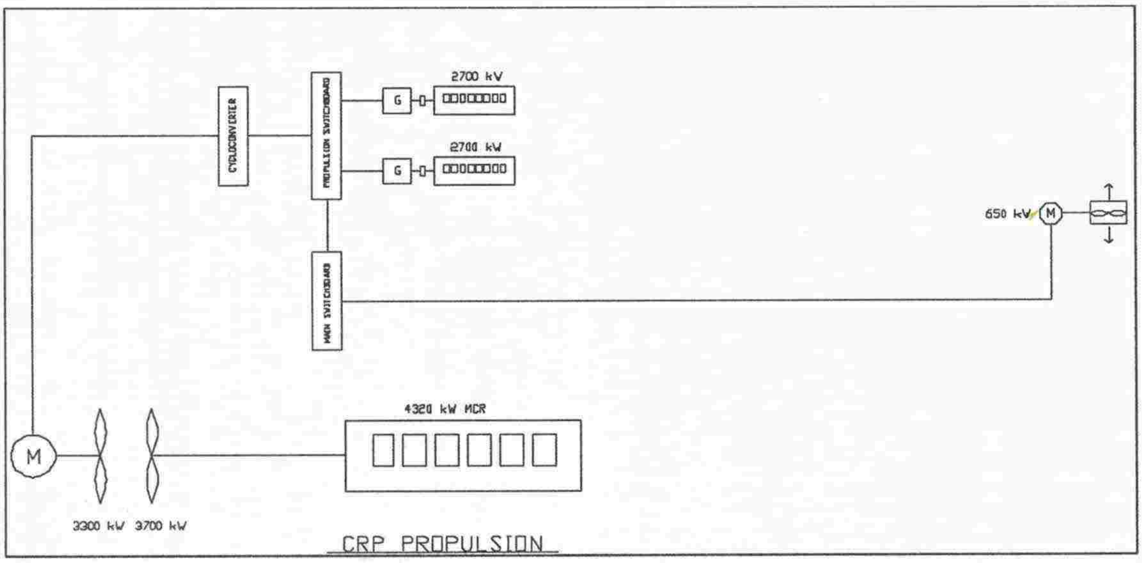

Figure 10 Machinery diagram

Steel structure

The vessel has a double hull, both double bottom and double sides. The sides are preferably transversally framed, the bottom, tank top, inner sides and deck may be longitudinally stiffened. High-strength steel may be used in areas, which are heavily exposed to ice loads, where the most benefit can be drawn. In the cargo holds, the tank top and the bulkheads are strengthened for heavy cargoes and the use of grabs.

Ice strengthening is done according to a minimum of IA Super standard, taking into account the double-acting method and independent operation in ice conditions. This means that the vessel will meet and break the ice itself, whilst a 'normal' IA Super class vessel meets ice in a channel that has already been broken by an icebreaker. Capability to withstand ice compression is checked, especially for the midship, and the magnitude of the ice strengthening may be increased in the stern for operation in high ice formations.

The underwater shell will be painted with wear-resistant Inerta-160 paint for increasing the life time of the paint, and to reduce the added ice resistance that may be caused by increasing the roughness of the shell.

Outfit

Deck cranes, 3 pcs., are of 25 tonnes/25 m outreach capacity, and grabs about 10 m^3. Small hydraulic telescopic knuckle boom cranes are installed on both sides as store/service cranes.

Cargo hatch covers are of the same width as the cargo holds, with hydraulically operated folding panels. For emptying and cleaning the holds, a wheel loader is delivered, provided with suitable lifting points and equipment.

Life-saving equipment consists of a free-fall lifeboat, life-rafts, floating apparatus in accordance with regulations, emergency suits, etc. In addition, a small work boat is installed.

2.3.1 Speed power prediction

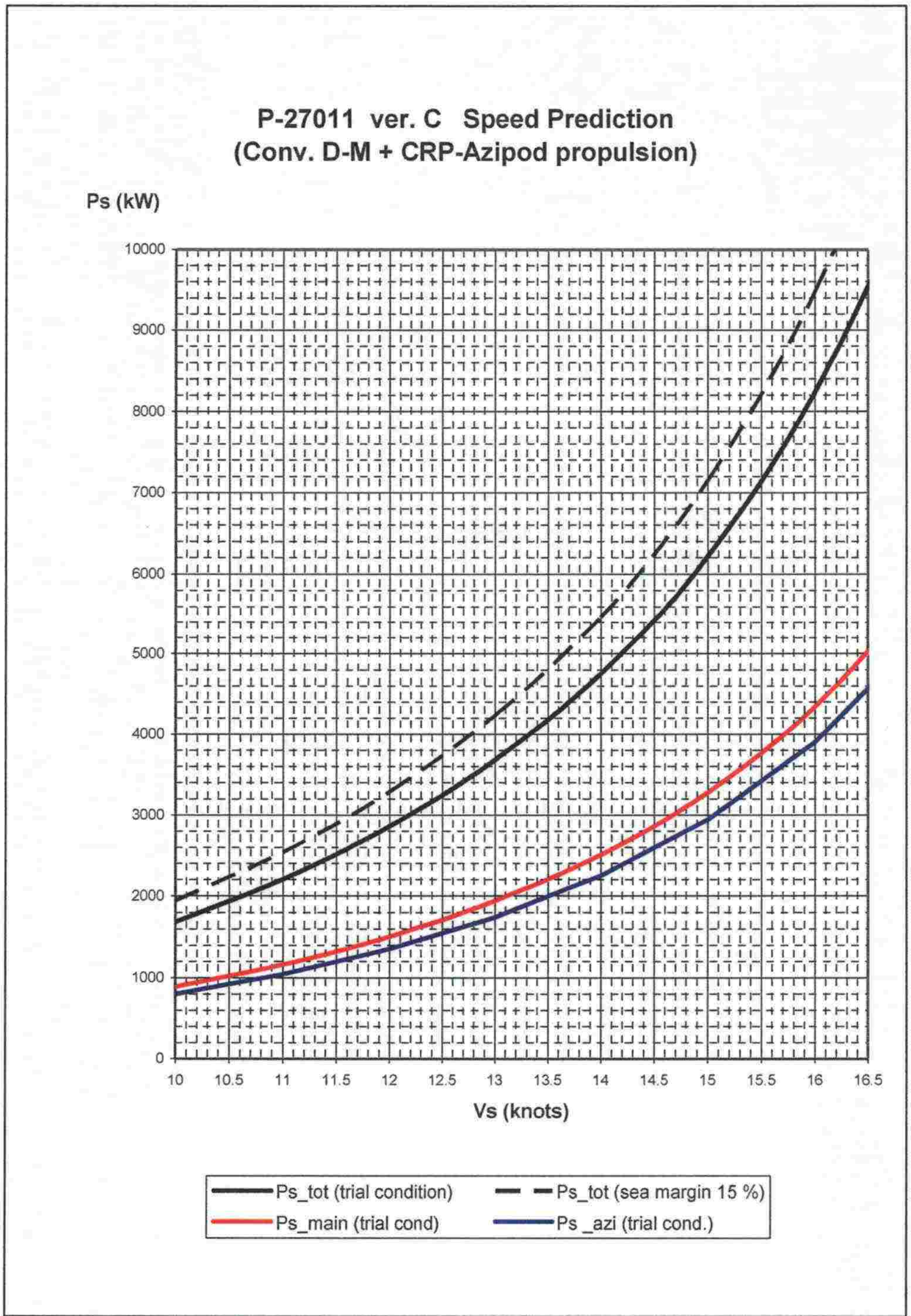

Figure 11 The propulsion power (kW) is calculated as a function of the ship speed (knots). The lower curve shows a trial prediction in still-water calm conditions. The upper dotted curve shows the power requirement with a 15% sea margin added to the trial prediction.

The red curve shows the power at the main propeller, and the blue line the power requirement at the azimuthing (crp) propeller in trial condition.

2.3.2 Icebreaking prediction

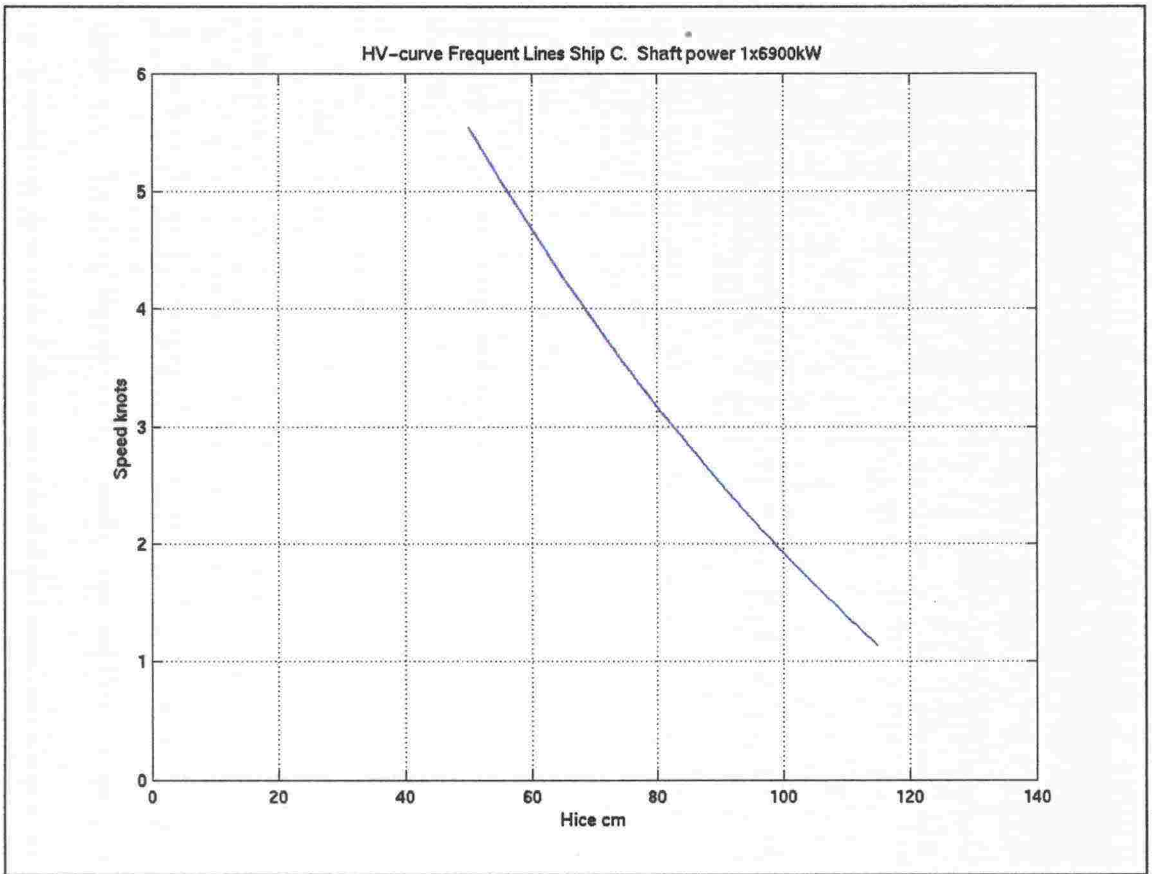

Figure 12 Speed – ice thickness (HV) plot for Double-acting CRP ship (astern)

In the prediction, the speed at the vessel's full operational power is shown in different unbroken level ice thicknesses. The C version is able to break up to 120 cm of ice at a speed of one knot. At a speed of 5 knots, it can break about 55 cm of ice.

2.4 IA Super ice class reference vessel

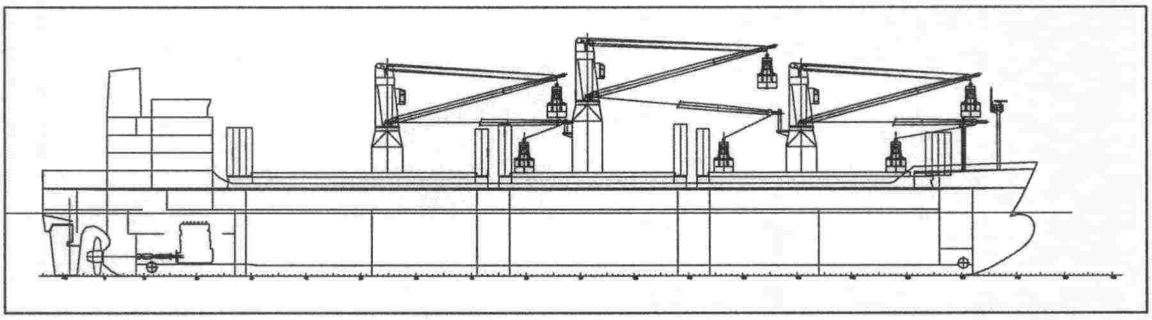

Figure 13 Side view of version O design. General arrangement drawing is shown in Appendix A.

For the reference design, a typical type of ice class bulk carrier is used. The design has a 16,000 tonne cargo capacity. This version has a bulbous bow and slow-speed diesel machinery with controllable pitch propeller.

Main Dimensions

Length oa	145.9 m
Length dwl	142.2 m
Beam	23 m
Draught	9 m
Depth	12.4 m

Performance

The MCR rating of the main engine is 8,280 kW. 15 knots service speed is achieved at about 6,300 kW, the main engine running at about 85 % power. Full-power trial speed is over 16 knots. At full power, the bollard pull force is about 110 tonnes.

In ice conditions, the vessel operates using the traditional method, always bow ahead. Reversing in ice conditions is restricted as for any normal cargo vessel.
Due to its bulbous bow, the icebreaking capability of the vessel is limited. Especially in unbroken level ice, breaking capability is only about 60 cm.

At a speed of 4 knots, the vessel is estimated to have an icebreaking capability of 40 cm.

Steering capability in ice conditions is limited as in any traditional type of vessel. In easy ice conditions and in open water at low speed, the turning capability can be improved using bow and stern thrusters.

Reversing capability is 'traditional'. In open water, reversing is difficult to control and, in ice conditions, reversing must be done with care and the rudder in the central position. The low reverse thrust of the cp-propeller may make it difficult to extract the vessel if it gets stuck when ramming.

Machinery

The machinery is similar to that in version A.

2.4.1 Speed power prediction

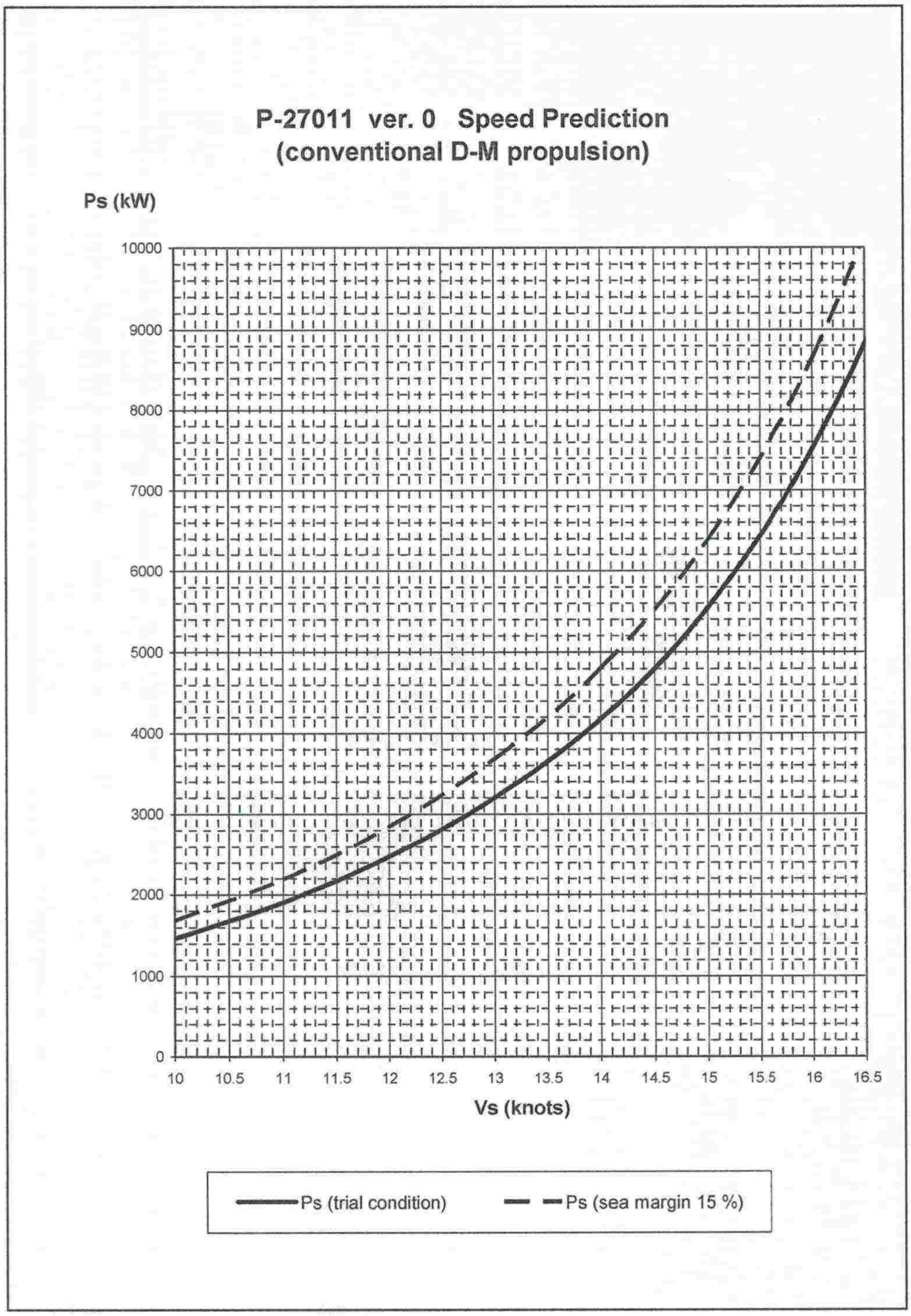

Figure 14 The propulsion power (kW) is calculated as a function of the ship speed (knots). The lower curve shows a trial prediction in still-water calm conditions. The upper dotted curve shows the power requirement with a 15% sea margin added to the trial prediction.

2.4.2 Icebreaking prediction

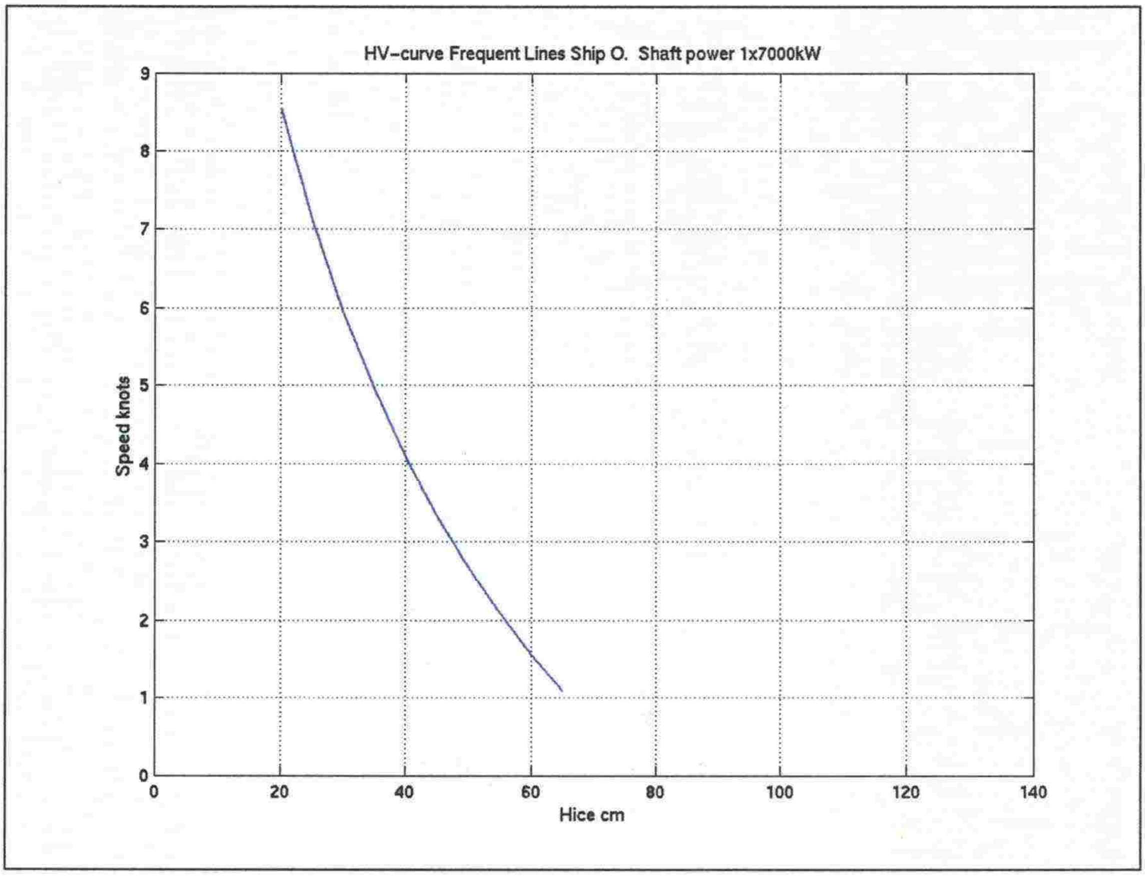

Figure 15 Speed - ice thickness (HV) plot for reference ship, version O (ahead)

In the prediction, the speed at the vessel's full operational power is shown in different unbroken level ice thicknesses. The O version is able to break up to 65cm of ice at a speed of one knot. At a speed of 5 knots, it can break about 35cm of ice.

3 Ship operational profiles

For the purposes of this study, the ship operational profiles must be determined. As the focus of the study is to provide comparative results for different vessel alternatives, mainly in independent ice navigation, determining ice conditions must be created. The proposed shipping route and ore transport between Sweden and Finland has been selected as the approach.

This chapter first provides a short description of the ice conditions on the shipping route during the normal mid-winter period. Then the numerical determination of the ice conditions is derived, and, finally, the speed and navigation performance of each vessel is calculated according to those conditions.

3.1 Shipping route

The shipping route is from the port of Raahe to the ore port of Luleå. The total distance of this route is 76 nautical miles. This distance can be covered only during the ice-free period, because, during the ice season, the ships must bypass the most difficult ice areas, and follow the easier areas and shipping lanes. This is often done by choosing an easier northerly route close to the area of firm ice. Figure 17 is a satellite image of typical ice conditions, showing the possible routes during winter operation. Figure 18 shows a typical sea-ice chart during March.

3.1.1 Ice channels

Both ports have some sheltering islands where the ice does not move, and thus a broken ice channel can be formed. This ice channel is longer in the Luleå part of the route. Towards the end of the winter, the channel gets thicker and thicker and makes navigation more difficult. Typically, ice channel thicknesses in the Raahe port area can grow up to 5 metres, making navigation very difficult. These ice channels have not been extensively studied and only a few measurements are available from references /5,6,7,8/, typically showing maximum thicknesses of over 4 metres. The most difficult part is the first 4 nautical miles from Heikinkari to Raahe lighthouse, which has an extensive ice formation.

The ice channel at the port of Luleå is somewhat easier, typically having a thickness no greater than 4 metres.

3.1.2 Sea ice

The sea ice in the area is not particularly thick, compared to the thicknesses of the firm ice near the shore. Sea ice typically increases to 50-70 cm during the most severe period of the winter /7/. A typical value of 50 cm will be used in this study to calculate the ships' performance on the route.

3.1.3 Pressure ridges

The pressure ridges and rafting of the ice, caused by the wind, occurs mostly at the mouth of the Raahe fairway. Ridging and high pressure on ice cause the greatest difficulties for ships. The ridges might have a total thickness of up to 15 metres in the area. Even constant vessel traffic is not able to keep the shipping routes open, because the ice is moving constantly and new ridges and ice areas are forming all the time. The ridged ice areas can not be avoided totally, and thus the vessels must be able to navigate through the ridges.

3.2 Determining ice conditions

For the purposes of this study, the route is divided into four different parts, each with different ice conditions, based on the descriptions in the previous chapter. The division of the legs is shown in Figure 16. The legs and the chosen ice conditions are listed in Table 3. In parts 1 and 4 of the legs, which are ice channel legs, the level ice thickness value represents the newly frozen ice layer. On the offshore sea legs the ridge fields are also determined. In leg 2, the average total ridge thickness (from sail to keel) is 7 metres and ridging intensity is 6 ridges per kilometre. In the other sea leg, which covers the majority of the distance (38 nm), the average ridge height is only 3 metres and 2 ridges per kilometre are met.

Table 3 Ice conditions for ships operation profiles

Ice property / Part of the route	Leg 1	Leg 2	Leg 3	Leg 4
Level ice thickness, m	0.20	0.40	0.40	0.20
Channel ice thickness, m	4.50	0.00	0.00	3.50
Ice concentration, %	100	100	95	100
Mean ridge thickness, m	0	7	3	0
Ridge density, ridges/kilometre	0	6	2	0
Distance of the leg, nm	4	5	57	10

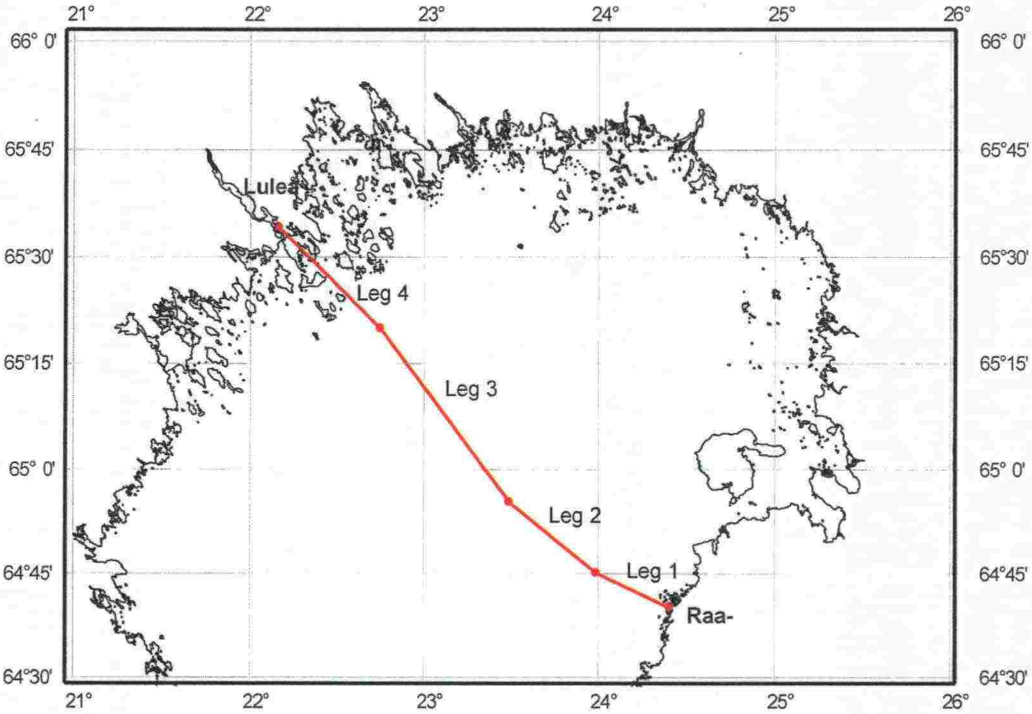

Figure 16 A map showing the division of ice conditions along the route

Compressed ice

Ice compression is not taken into account in the performance calculations. It is well known that compression will have a significant effect on ship speed. The ship versions designed have different levels of capability to navigate in ice compression. The DAS versions B and C have a better capability to withstand the compression, and they are able to navigate in higher ice compression than reference and icebow vessels. The DAS propulsion system provides a good water-flushing effect that reduces the ice contact between the ship hull and the ice. This, together with excellent manoeuvring capability, helps navigation in compressed ice.

Figure 17 is a satellite image showing typical ice conditions in the Gulf of Bothnia. The lines in the image show shipping routes used to sail the shortest route. Any one of the indicated routes is used depending on the ice and wind conditions prevalent at the time.

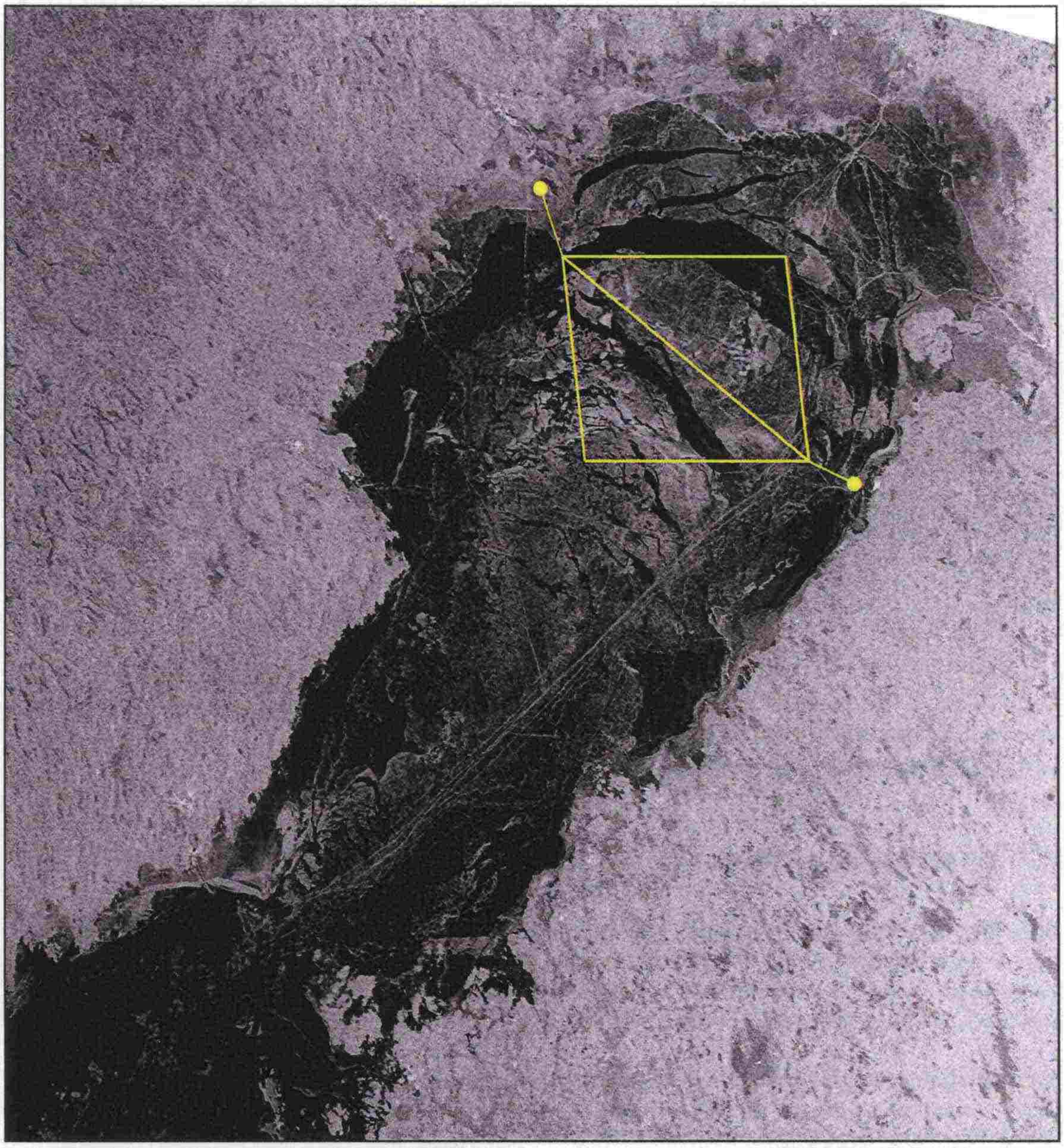

Figure 17 Satellite image of the ice conditions in the Gulf of Bothnia (RadarSat March 2006)

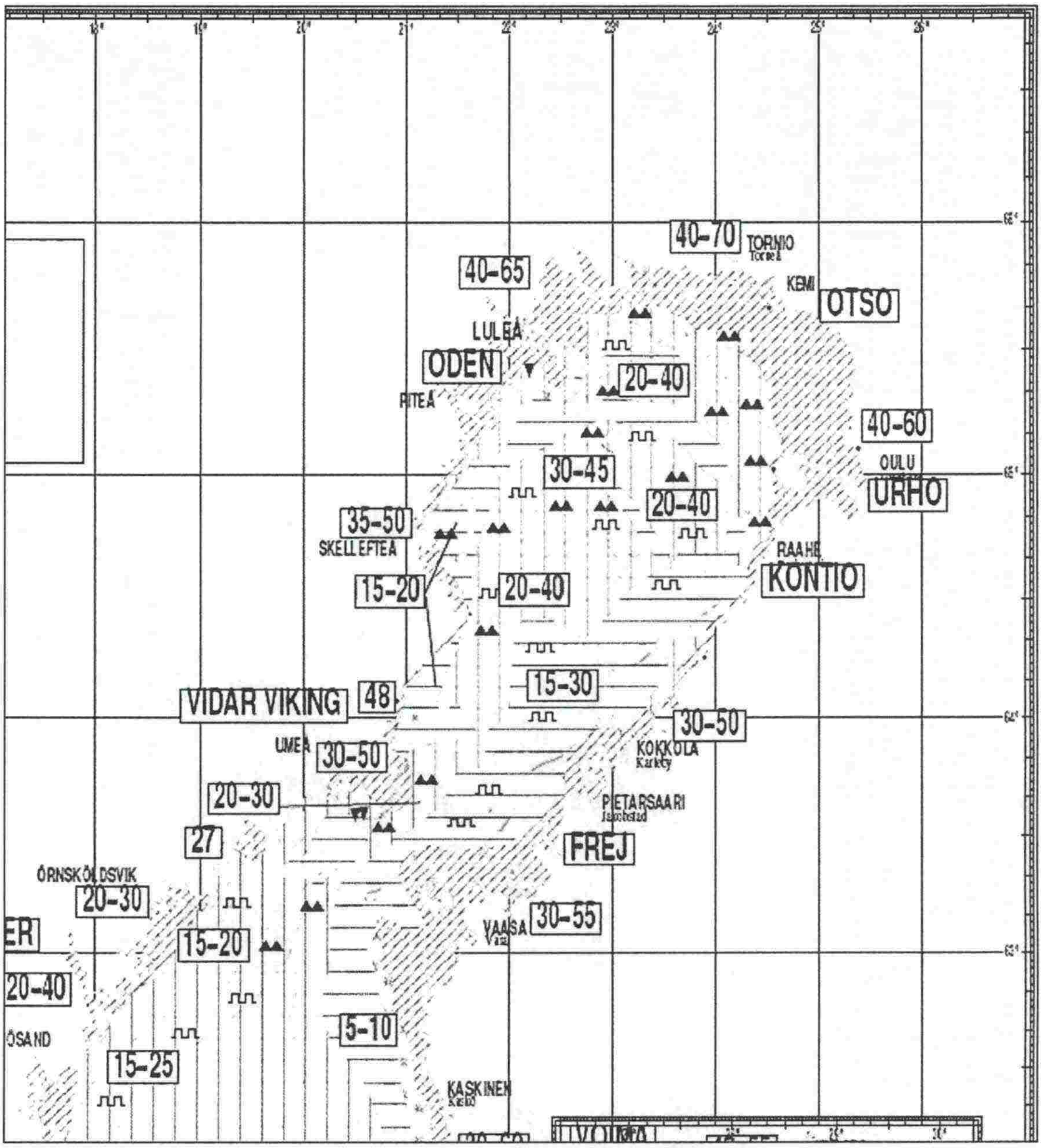

Figure 18 Sea ice chart from 15th March, 2006.
(source: http://www.smhi.se/)

3.3 Operational profiles

Ship operational profiles are needed for operative fuel consumption estimates. Based on environmental conditions in the area, the ice coverage typically lasts from December to April. During this period the ice has a significant effect on ship navigation and, thus, speed and use of power.

For the operational profiles, 5 months are considered as the ice navigation period, and 7 months as open-water season. Based on the vessels' open water speed and ice navigation capability, the number of round-trips is estimated for year-round operation. The same number of round-trips is used in the comparison, and the correct amount of fuel can be calculated.

However, it should be noted that a vessel with higher speed through ice can make more trips during the winter, but this economical investment benefit is not taken into account in this comparison.

3.3.1 Icebreaking simulation

Different concept alternatives have a different capability to operate in ice. The capability to navigate through the ice was determined using estimates for ice- breaking capability described in Chapter 0. Based on those estimates, a computer simulation programme was used to model ship navigation through ice-covered waters. With this special purpose programme, the ship's speed profile can be determined accurately in a specified ice profile. The ice conditions can contain various ice types, level ice, broken ice, ridged ice, floe ice and channel ice. Furthermore, the ship itself with its machinery and propulsion capabilities is modelled by computer simulation. From the ice conditions determined in Table 3, ice profiles were generated for the purposes of simulation. Finally, the different ships were simulated to find out the speed that the vessels can reach in ice.

Figure 19 to Figure 21 present the plots from simulation, showing the speed profile achieved. The plots from ice leg 2 are shown, containing both ice ridges and level ice. The actual leg is 5 nautical miles long but, for the simulation, 20 km (10.8 nm) distance was simulated in order to gain good accuracy for the average speed. The upper plot shows the ship speed, and lower plot the ice conditions with the blue line showing level ice and green line showing the ridges.

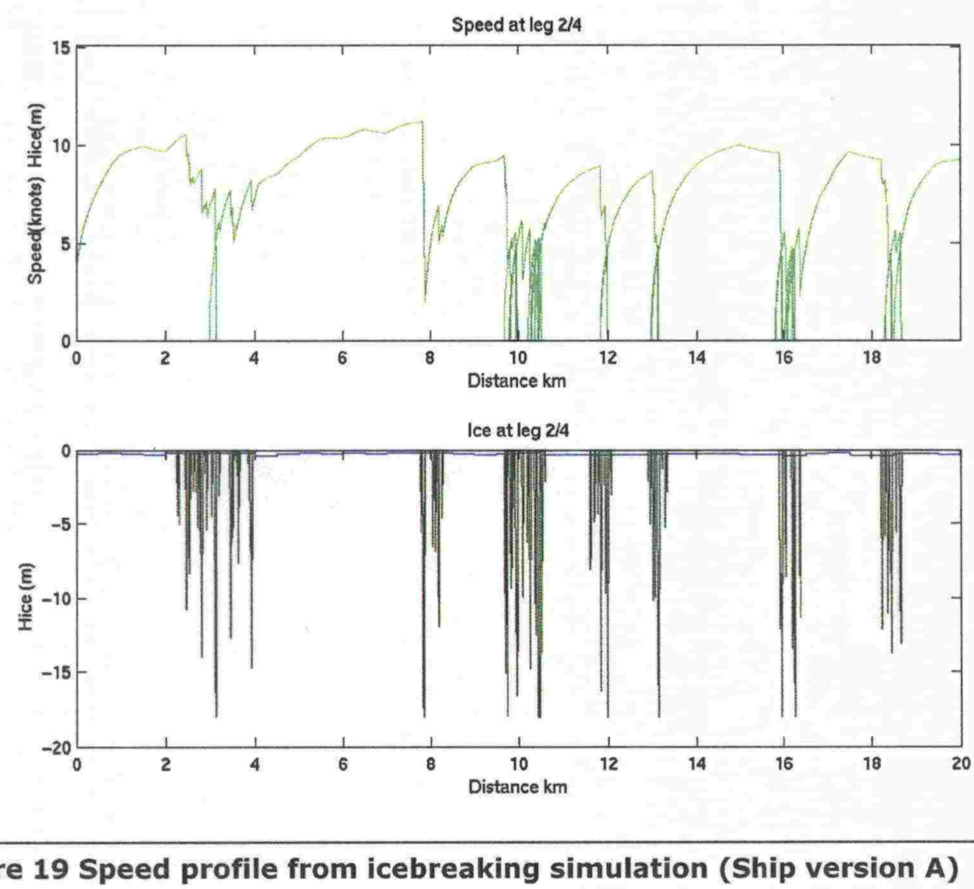

Figure 19 Speed profile from icebreaking simulation (Ship version A)

The simulation shows that the vessel stops several times. The only way for the vessel to proceed is to use ramming to get through dense ridge fields. This can be seen in positions 3, 10, 12, 13, 16 and 18 kilometres.

Based on this result, it could be said that the vessel is in principle able to navigate through the specified ice conditions. The speed of the ship (traditional icebow vessel), however, drops to zero at the worst ridges and is forced to stop, and it is only able to continue by ramming. This type of operation is extremely rare for normal ice-class cargo vessels, and carries an increased risk of damage to the propulsion system or hull structure. Also, the ice pressure effects could not be taken into account in the simulation, and it could be expected that ramming in pressure ice with this type of cargo vessel would be possible. The reversing of the vessel from the ice ridges would most probably be impossible.

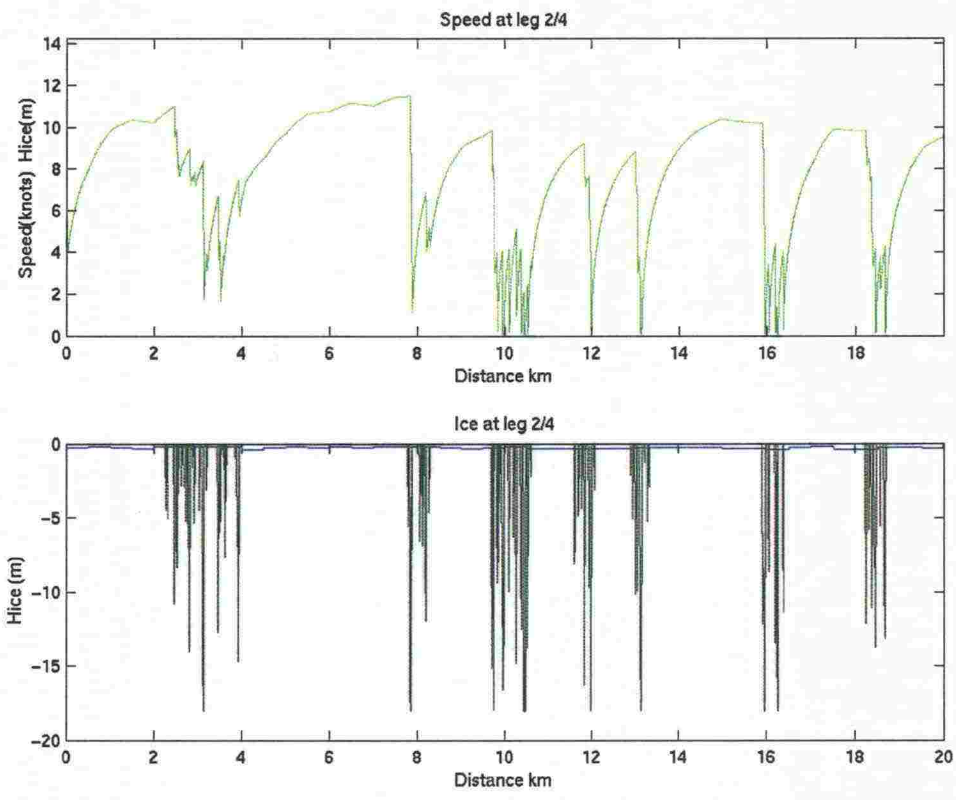

Figure 20 Speed profile from icebreaking simulation (version B) in astern operation

The simulation for the Double-acting vessel version (B) also shows the dramatic speed drop at the same dense ridges as in version A. However, the benefit of the Double-acting icebreaking principle is that vessel is able to penetrate the ridge areas without ramming, at low but constant speed. This could also be obtained from the simulation plot, and several full-scale ship observations demonstrate the same behaviour.

Even in mild ice compression situations, the ship's good manoeuvring ability and the ice-flushing effect of the propulsion device help the vessel not to get stuck in ice fields.

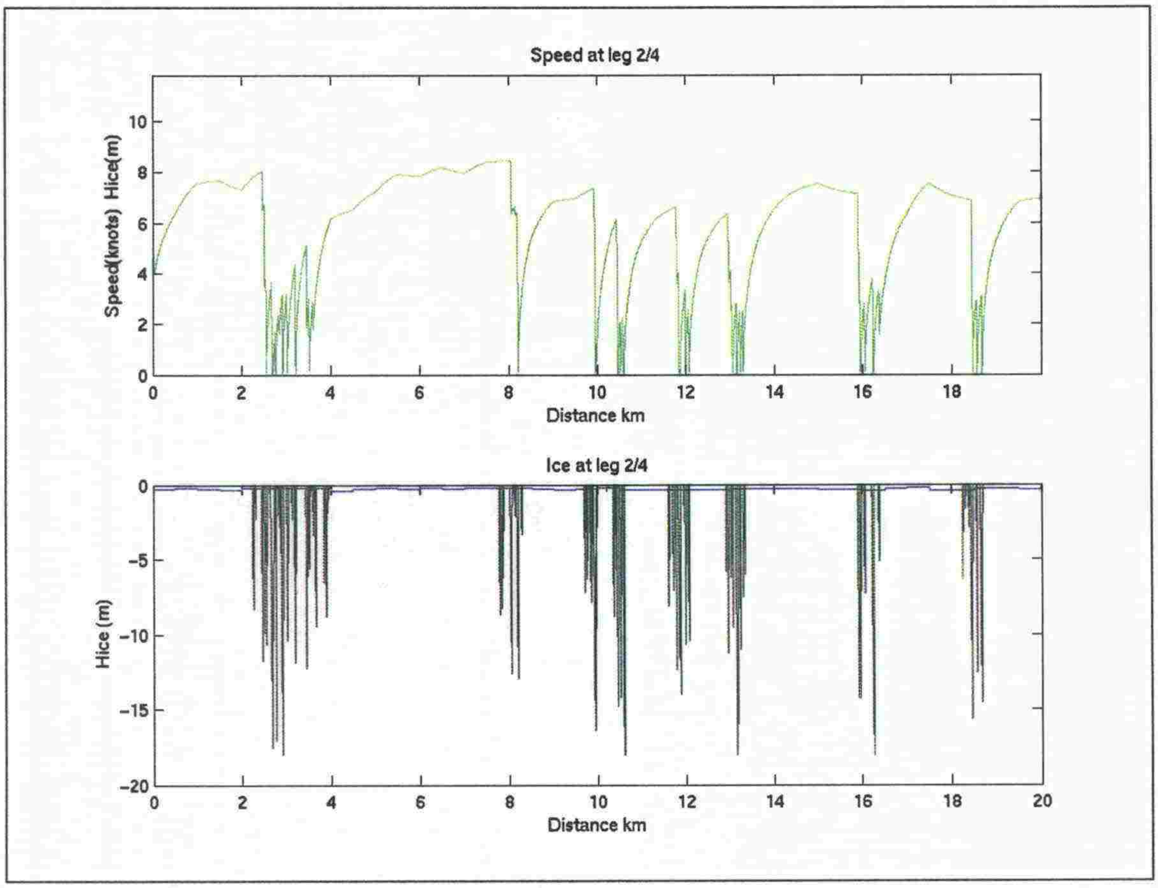

Figure 21 Ship version C, Double Acting CRP-propulsion, astern operation

CPR propulsion in version C also behaves similarly in ice conditions as version B, but at somewhat lower speed due to the lower bollard pull of the vessel and slightly reduced water-flushing effects. The result according to simulation, however, shows an acceptable speed for independent ice navigation without ramming operation.

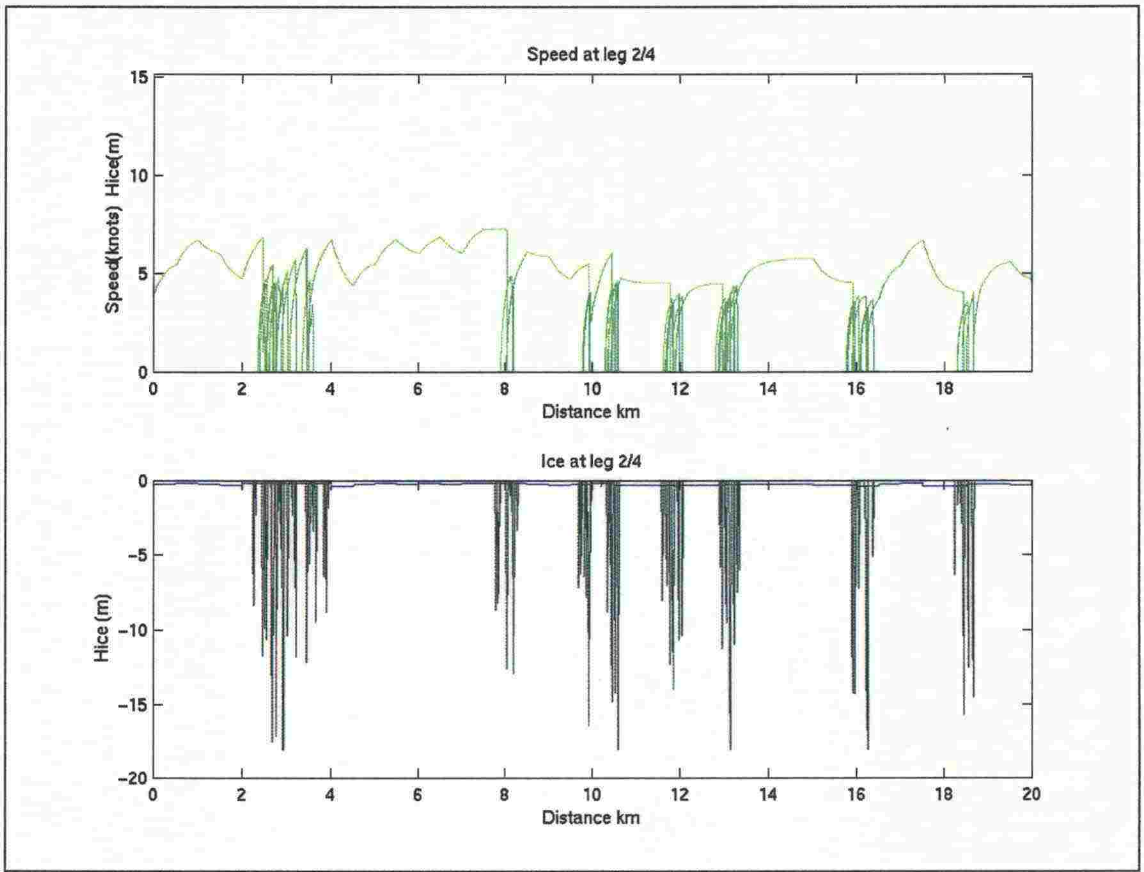

Figure 22 Ship version O, reference vessel with bulbous bow form, ahead operation

3.3.2 Results of icebreaking simulation

All the specified ice legs were simulated for three vessel alternatives, and the average speed achieved is presented in the following table.

Table 4 Average speed for each simulated leg

Results from simulation	LEG 1	LEG 2	LEG 3	LEG 4	
Distance	4	5	57	10	nm
Version A, shaft line	0.00	4.17	10.14	2.59	knots
Version B, DAS propulsion	1.92	6.62	10.31	2.88	knots
Version C, CRP propulsion	0.5	4.5	7.63	0.89	knots
Version O, reference	0	1.92	5.86	0	knots
Version A, shaft line	stuck	1.2	5.6	3.9	hours
Version B, DAS propulsion	2.1	0.8	5.5	3.5	hours
Version C, CRP propulsion	8.0	1.1	7.5	11.2	hours
Version O, reference	stuck	2.6	9.7	stuck	hours

It can be seen, that for the vessels A, C and O, the first leg (channel ice 4.5 m) seems to be practically impossible. A traditional icebow vessel is not able to proceed at all despite its effective well-designed icebow form. It can be concluded that the vessel needs an icebreaker to assist it out from the channel.

Neither is the CRP version vessel able to maintain good speed, despite its Double-acting principle. The main reason is that the propulsion thrust of the CRP solution is insufficient for the thick ice channel. This could be corrected by dimensioning the power accordingly or by utilising icebreaker assistance during the most difficult period of the year. The reference vessel with the bulbous type hull form is not able to proceed through thick ice channels at either end of the route.

Based on the results it can be concluded that vessel A will need to utilise ice breaker assistance, both in the Raahe ice channel (5 m thick) and during the off-shore crossing in heavy ridge conditions. Cargo vessels can not utilise ramming in practice. Ship version C (CRP propulsion) will need the icebreaker only in the thick Raahe channel. Reference vessel O will need icebreaker assistance during dense ridge fields, and can operate independently only in mild ice conditions.

Based on the simulation results, the following operational types and speeds (Table 5) can be concluded and used further in the fuel consumption calculations.

Table 5 Speed and assistance used in fuel consumption calculations

Operation profiles		LEG 1	LEG 2	LEG 3	LEG 4	
	Distance	4	5	57	10	nm
Version A	speed	2.00	4.20	10.14	2.59	knots
	oper. type	assisted	assisted			
Version B	speed	1.92	6.62	10.31	2.88	knots
	oper. type					
Version C	speed	2.00	4.50	7.63	0.89	knots
	oper. type	assisted				
Version O	speed	2.00	3.90	10.00	2.30	knots
	oper. type	assisted	assisted		assisted	

3.3.3 Operation profiles for fuel consumption estimates

Operational profiles are used to calculate the vessels' time and fuel consumption. Because the DAS ship (version B) is able to navigate without icebreaker assistance in all conditions, the speed obtained from simulation can be used as such. But for the versions A, C and 0, the use of icebreaker assistance must be evaluated. The simulation program is not able to handle such a complex operation. Instead, an approximate value is used. Taking into consideration the difficult ice conditions and operational experience, an average speed of 2.0 knots is used for the assisted vessels in the Raahe ice channel. For the reference vessel (version 0), the speed in assisted navigation in open sea is assumed to average 8.8 knots. Otherwise the speeds are taken from the simulation programme.

During the summer season, the vessels navigate on the coastal fairways at a speed 12 knots. In the open sea area, the full service speed of 15 knots is used.

Table 6 to Table 9 shows the operation profiles of the different ship design alternatives with the machinery power levels to be used in the fuel consumption and emission calculations.

Table 6 Operation profiles for vessel A

Vessel / mode	Speed (knots)	Needed power at propeller (kW)	Main engine power (kW)	Auxiliary power (kW)
A. Conventional				
Normal winter season				
Port operation	0.0	0	0	600
Manoeuvring	0.0	3000	3061	1900
Ice channel 1	2.0	7000	7143	600
Ridged ice	4.2	7000	7143	600
Level ice	10.1	7000	7143	600
Ice channel 2	2.6	7000	7143	600
Manoeuvring	0.0	3000	3061	1900
total.				
per round-trip:	-	-	-	-
per season (40 round-trips):	-	-	-	-
Icebreaker assistance 200 h/per season (ref. vessel Kontio)				
Open season				
Port operation	0.0	0	0	600
Manoeuvring	0.0	3000	3061	1900
Slow speed	12.0	2950	3010	600
Service speed	15.0	7000	7143	600
Manoeuvring	0.0	3000	3061	1900
total.				
per round-trip:	-	-	-	-
per season (68 round-trips):	-	-	-	-

Table 7 Operation profiles for vessel B

Vessel / mode	Speed (knots)	Needed power at propeller (kW)	Main engine power (kW)	Auxiliary power (kW)
B. DAS Azipod				
Normal winter season				
Port operation	0.0	0	0	600
Manoeuvring	0.0	-	4000	0
Ice channel 1	1.9	7600	8866	0
Ridged ice	6.3	7600	8866	0
Level ice	10.3	7600	8866	0
Ice channel 2	2.9	7600	8866	0
Manoeuvring	0.0	-	4000	0
total.				
per round-trip:	-	-	-	-
per season (40 round-trips):	-	-	-	-
Open season				
Port operation	0.0	0	0	600
Manoeuvring	0.0	-	4000	0
Slow speed	12.0	3600	4525	0
Service speed	15.0	7600	8866	0
Manoeuvring	0.0	-	4000	0
total.	-	-	-	-
per round-trip:	-	-	-	-
per season (68 round-trips):	-	-	-	-

Table 8 Operation profiles for vessel C

Vessel / mode	Speed (knots)	Needed power at propeller (kW)	Main engine power (kW)	Auxiliary power (kW)
C. DAS CRP				
Normal winter season				
Port operation	0.0	0	0	600
Manoeuvring	0.0	-	0	4544
Ice channel 1	2.0	3670/3300	3673	4200
Ridged ice	4.5	3670/3300	3673	4200
Level ice	7.6	3670/3300	3673	4200
Ice channel 2	2.0	3670/3300	3673	4200
Manoeuvring	0.0	-	0	4544
total.				
per round-trip:	-	-	-	-
per season (40 round-trips):	-	-	-	-
Icebreaker assistance 100 h/per season (ref. vessel Kontio)				
Open season				
Port operation	0.0	0	0	600
Manoeuvring	0.0	-	0	4544
Slow speed	12.0	1800/1600	1837	2355
Service speed	15.0	3300/3000	3367	3874
Manoeuvring	0.0	-	0	4544
total.	-	-	-	-
per round-trip:	-	-	-	-
per season (68 round-trips):	-	-	-	-

Table 9 Operation profiles for vessel O

Vessel / mode	Speed (knots)	Needed power at propeller (kW)	Main engine power (kW)	Auxiliary power (kW)
0. Reference				
Normal winter season				
Port operation	0.0	0	0	600
Manoeuvring	0.0	3000	3061	1900
Ice channel 1	2.0	6400	6531	600
Ridged ice	3.9	6400	6531	600
Level ice	10.0	6400	6531	600
Ice channel 2	2.3	6400	6531	600
Manoeuvring	0.0	3000	3061	1900
total.				
per round-trip:	-	-	-	-
per season (40 round-trips):	-	-	-	-
Icebreaker assistance 400 h/per season (ref. vessel Kontio)				
Open season				
Port operation	0.0	0	0	600
Manoeuvring	0.0	3000	3061	1900
Slow speed	12.0	2850	2908	600
Service speed	15.0	6400	6531	600
Manoeuvring	0.0	3000	3061	1900
total.				
per round-trip:	-	-	-	-
per season (68 round-trips):	-	-	-	-

4 Fuel consumption and emission calculations

Fuel consumption is calculated for each vessel alternative. The basis for calculation is that each vessel type will sail the same number of round-trips per year, which is 40 during the winter and 68 during the summer. The purpose of this definition is to have fuel and emission results comparable for each vessel. In practice, the designs with better icebreaking capability could sail more round-trips per year, and thus make better profit for the investment.

Emissions and fuel consumption are calculated based on the defined operational profiles (Chapter 3.3.3). Further emissions are converted to an emission cost index, which is presented in euros. Conversion is based on the emission cost values from reference /8/.

Table 10 shows the emissions components for the different engine types. A 2-stroke main engine is used in versions A and C. 4-stroke engines are used in version B. Factors are based on LSF (low sulphur fuel) heavy fuel oil. New requirements from MARPOL Annex VI define the Baltic Sea as a SECA area where sulphur content may not exceed 1.5%.

The emission cost index is based on different areas of pollution where the harbour and coastal areas will have a different value than offshore sea areas. This division is taken into account in the emission cost calculation. Cost (euro/t) values for the emissions are shown in Table 11. Results for the actual fuel consumption cost and emission cost are summarised in Table 12.

Table 10 emission factors (g/kWh) /9/

Component	2-stroke engine	4-stroke engine
CO	0.60	1.00
HC	0.39	0.39
NO_x	16.8	13.3
Particles	0.48	0.29
CO_2	588	608

Note. 1% used as a sulphur content for heavy fuel oil and 0,15% for marine diesel oil

Table 11 Specified cost values for different components (euro/t) /8/

Component	Harbour	Coastal area	Open sea
CO	19	2	0.4
HC	148	153	137
NO_x	1062	397	301
Particles	26880	5610	3410
CO_2	32	32	32
SO_2	2283	547	327

Note: Fuel costs calculated based on price 300 EURO / tonne

Table 12 Fuel and emission costs for each vessel alternative

		Round-trip based		Yearly based		
Vessel / mode	Period	Fuel costs total eur	Environm. costs total eur	Round-trips / year	Fuel costs total eur	Environm. costs total eur
A. Conventional	Winter	11894	6812	40	475765	272476
	Summer	5380	3234	68	365830	219946
+ Icebreaker	Winter	4365	2119	40	174600	84780
	Total	**21639**	**12166**	**108**	**1016194**	**577202**
B. DAS Azipod	Winter	13280	6966	40	531217	278637
	Summer	6285	3492	68	427351	237457
	Total	**19565**	**10458**	**108**	**958568**	**516094**
C. DAS CRP	Winter	14819	8052	40	592758	322091
	Summer	5330	3147	68	362410	213969
+ Icebreaker	Winter	2183	1060	40	87300	42390
	Total	**22331**	**12259**	**108**	**1042468**	**578450**
0. Reference	Winter	11583	6648	40	463331	265903
	Summer	5103	3091	68	347004	210216
+ Icebreaker	Winter	8730	4239	40	349200	169560
	Total	**25416**	**13978**	**108**	**1159536**	**645679**

All the new designs (A, B and C) have lower fuel and emission costs than the reference vessel. Fuel cost saving can be as much as 30% for the most economical solution.

The results show the lowest fuel consumption for the vessel alternative B. For one round-trip, the cost is approximately 30% less than for the reference vessel. The same relative saving is also in the environmental cost. In the overall yearly operation, the cost saving in fuel is approximately EUR 201,000. The environmental cost saving is about EUR 130,000. Both these values are for one ship operating 108 round-trips per year.

5 Ship cost estimates

The ship cost estimates are based on European shipyard cost levels. The pricing of the vessel is divided into 4 categories: design work, hull construction, outfitting and machinery component cost. The main difference between the options is the outfitting and machinery costs. The DAS bulker has the highest cost in total and in machinery, due to its Azipod propulsion system and completely diesel-electric propulsion. Estimates for the vessel cost are shown in Table 13.

Table 13 Ship cost estimates based on European construction

Item	Description	Vessel A	Vessel B	Vessel C
DESIGN	DESIGN AND CLASSIFICATION COSTS	4 900	5 000	5 100
HULL	STEELWORK INCL. PAINTING	21 000	22 000	21 600
OUTFIT-TING	OUTFITTING	10 000	12 000	12 500
MACHIN-ERY	MACHINERY excl. OUTFITTING COSTS	7 940	14 540	10 370
Total	kEUR	43 840	53 540	49 570

Table 14 Cost estimate for reference vessel based on European construction

Item	Description	Reference vessel 0
DESIGN	DESIGN AND CLASSIFICATION COSTS	4 900
HULL	STEELWORK INCL. PAINTING	20 700
OUTFIT-TING	OUTFITTING	10 000
MACHIN-ERY	MACHINERY excl. OUTFITTING COSTS	7 940
Total	kEUR	43 540

6 Future development needs for the concepts

All the ship designs presented in this report are done at conceptual level. The purpose of the designs is to have the required information about the vessels' icebreaking capability, fuel consumption, icebreaker need, estimation of the new-building cost and, last but not least, the difference between the alternatives. However, during the design work, technical components or solutions were considered, which require further development before the actual commercial actions can be made.

The traditional and the reference versions have no such technical solutions, which would not be available today at most modern shipyards.

The DAS vessel is also well proven technology, and recently a similar type /2/ of the vessel was delivered to Russia, which had higher ice-class and operational requirements. Thus, the technology and components needed for the DAS-type bulk carrier are available today at most modern shipyards.

The CRP-DAS solution is a completely new type of propulsion system in icebreaking vessels. The conceptual operability of such a system was initially model-tested at Aker Arctic Test Laboratory and the general idea was proven. The technical definition of the propulsion system is not stated in this study, and several open questions should be confirmed before the actual decisions are made. The CRP concept has poor thrust capability in astern operation, thus reducing its icebreaking capability. What the actual level of thrust, and therefore correct engine selection, would be is somewhat open and requires a further test programme.

Furthermore, the solution will require a pulling ice-strengthened azimuth propulsion unit. These types of units are not necessarily available without some investments in development work. It is not envisaged that any major technical barriers would exist. The ice loads that the propulsion unit will face should also be evaluated by scale model and operational measurements. Despite the aforementioned development needs, the benefits of such a solution are clear, with lower cost for the propulsion device and improved fuel economy in open- sea operation.

7 Comparison and conclusions

The aim of this study was to compare investment and operational costs and environmental impacts for winter shipping in the Northern Baltic and Gulf of Bothnia traffic. The approach was to make three modern and efficient vessel designs for ore transport between the ports of Raahe and Luleå, and compare them to a typical reference vessel used today.

Vessel types designed in this work are general bulk cargo vessels, with 3 cargo holds and 3 deck cranes for cargo handling. Vessel designs are not restricted to ore cargo, but are designed for general bulk cargo. All the designs have exceptionally good ice-going capability. The main dimensions are 153 m in length, 23 m breadth and a maximum draught of 9.0 m. All the designs are made for Finnish-Swedish ice class IA Super, but will have very different icebreaking capabilities.

The first vessel version (A) is a traditional icebow vessel with a single CP propeller and a slow-speed diesel engine.

The second design (B) utilising Double-acting icebreaking technology with azimuthing propulsion and icebreaking is done by running the vessel astern. It has been demonstrated that the cargo vessel is capable of independent icebreaking even in difficult Arctic ice conditions, using this technology.

The third version (C) is similar to B, but is equipped with CRP-propulsion, which gives good open-water efficiency and lower operating costs compared to a full Double-acting vessel.

The reference vessel (O) is a typical bulbous bow vessel with a slow-speed engine and a single CP propeller.

In the work, the icebreaking performance calculations were carried out for all four alternatives, and, by using a simulation programme, the capability of the vessels to navigate through frozen sea was investigated. The calculations show that all new vessel designs have very good breaking capability in level ice. However, the simulations reveal that the icebow vessel (A) is not able to navigate independently through the ice ridges in the Gulf of Bothnia. Also, the very difficult coastal channel to the port of Raahe causes trouble for the traditional type vessel (A), version O and also for the CRP-version vessel (C). Thus, the conclusion is that navigation without icebreaker assistance is not practically possible for versions A and O.

The ice conditions where the vessels should be able to operate are defined in the study. Level ice thickness, frozen ice channels and ridge fields in the moving ice areas are incorporated into the calculations. This definition is much wider and more comprehensive compared to what is used in the current ice class rules. It is proposed that those vessels, which fill the operability requirements stated in this study, can be considered as capable of independent winter navigation without the need for icebreaker assistance.

The fuel consumption values for the alternatives are based on direct calculations. The basis for year-round navigation is a total of 108 round-trips, where 40 will be in the winter season. Results show that vessel version B will have the lowest annual fuel cost, EUR 954,000. For the icebow vessel (A), the fuel consumption of the icebreaker will increase the cost significantly and the total fuel cost will be EUR 1,186,000. The CRP vessel (C) falls in between, having an annual cost of EUR 1,036,000. The reference vessel (O) has a fuel cost of EUR 1,159,000. It should be noted that this cost calculation is purely for fuel cost, and does not include any manning or other operative or investment costs.

The cost index for emissions correlates with direct fuel costs. The environmental cost is EUR 535,000 for the DAS vessel (A), whereas the traditional vessel (O) has a cost of EUR 711,000, which includes an EUR 169,000 emission cost for the ice-breaker. The use of a slow-speed diesel engine in versions A and O increases the environmental effect together with the increased time and fuel consumed at sea. The CRP version (C) falls between the previous version with a cost index of EUR 634,000, including the icebreaker emission cost of EUR 42,000.

Based on both fuel and environmental effects, the advantage of independent ice-breaking operation (i.e. without icebreaker assistance) is clearly shown. The difference in direct fuel cost is only about 32% in favour of the independent vessel solution.

Table 15 Summary of fuel and environment costs

Vessel / mode	Fuel costs total euro	Environm. Costs total euro
A. Icebow	**1,016,194**	**577,202**
B. DAS Azipod	**958,568**	**516,094**
C. DAS CRP	**1,042,468**	**578,450**
0. Reference	**1,159,536**	**645,679**

Table 16 Daily and annual fuel consumption values

FUEL CONSUMPTION SUMMARY				
Vessel / mode	tonne/day	Cargo vessel tonne/year	Icebreaker tonne/year	Total tonne/year
A. Icebow	**32.6**	**2805**	**582**	**3387**
B. DAS Azipod	**39.2**	**3195**	**0**	**3195**
C. DAS CRP	**31.5**	**3184**	**291**	**3475**
0. Reference	**30.3**	**2701**	**1164**	**3865**

Investment in a modern and efficient fleet is obviously more expensive. Price indications for vessel B show an investment nearly EUR 10 million higher compared to the traditional vessel O (20%). However, looking at the overall picture from the point of view of national economy, and including the fuel and environmental cost and especially the icebreaker investment cost (EUR 50-70 million) as well as manning expenses, the independent cargo vessel alternative would be a suitable solution in Gulf of Bothnia shipping operations.

Table 17 Investment cost for cargo vessels and icebreakers

Vessel type	Price Million euro	Price, icebreaker Million euro
A. Icebow	**43,8**	**Approx. 70**
B. DAS Azipod	**53,5**	**0**
C. DAS CRP	**49,5**	**0**
0. Reference	**43,5**	**Approx. 70**

The cost of the icebreaker operation can be calculated simply by using the number of operation days and the day rate (EUR 30,000). This cost could be saved by using independent cargo vessels. The amount of saving would be about EUR 2.7 million per year in the case of the route considered in this study. This example calculation gives an indication of the size of a possible subsidy for operators investing in independent cargo vessel

Table 18 Icebreaker day cost (based on 3 months ice period)

Day cost Euro	Operation Days	Annual Cost Euro
30,000	90	2,700,000

Table 19 Annual fairway dues calculated for a vessel at 5,326 NRT, Finland, Corresponding to10,950 GRT, Sweden

Annual fairway dues for a 5,326 NRT vessel		
Finland	72,400	EUR
Sweden	184,000	EUR
Total	**256,400**	**EUR**

As long as there is no economic incentive for the shipping operators to absorb the additional 10-20% higher investment cost, it is very unlikely that any such investment decisions will be made. All types of vessels fulfil IA Super ice class and are paying the same amount of fairway dues, irrespective of their actual need for icebreaker assistance. The dues are based on the ship's Net Register Tonnage for calculations in Finland, which correspond to a Gross Tonnage of approximately 10,950, used for calculations in Sweden, and the number of voyages. In Sweden, there are fairway dues on the cargo as well, which is not limited to the number of voyages. This explains the big difference between the fairway dues in Finland and Sweden on this high frequent line. The values both for Finland and Sweden are shown in Table 19. This will be the amount, which the ship operator would save if the vessel were exempt from fairway dues. The saving cannot be considered sufficient to cover the higher investment cost, therefore other incentive schemes should be created for the operators of independently operating vessels. The definition of contractual icebreaking capability must be determined carefully, and the vessels should be able to prove their icebreaking capability in order to be categorised as an independent icebreaking cargo vessel.

ABBREVIATIONS

AARC	Aker Arctic Technology Inc.
CRP	Contra Rotating Propulsion
DAS	Double-acting Ship
D-E propulsion	Diesel Electric Propulsion
D-M propulsion	Diesel Mechanical Propulsion
FMA	Finnish Maritime Administration
HV-curve	Icebreaking curve, ice thickness (H) versus speed (V)
kW	Kilowatt
LSF	Low sulphur fuel
MARPOL	International Convention for the Prevention of Pollution
MCR	Maximum Continuous Rating
Ps	Power on Shaft
SECA	SOx Emission Control Area
Vs	Ship speed

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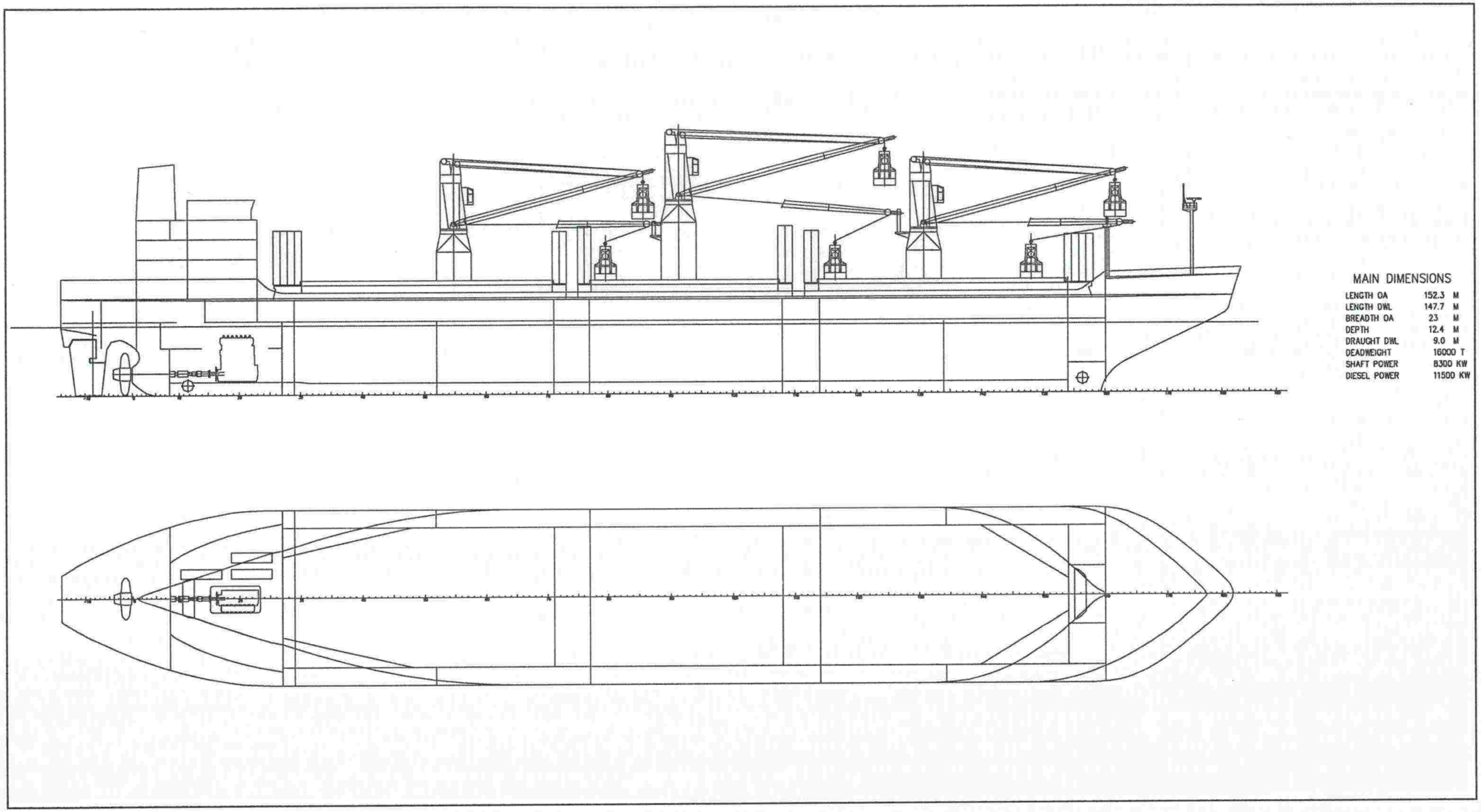
APPENDIX A

SHIP VERSION A



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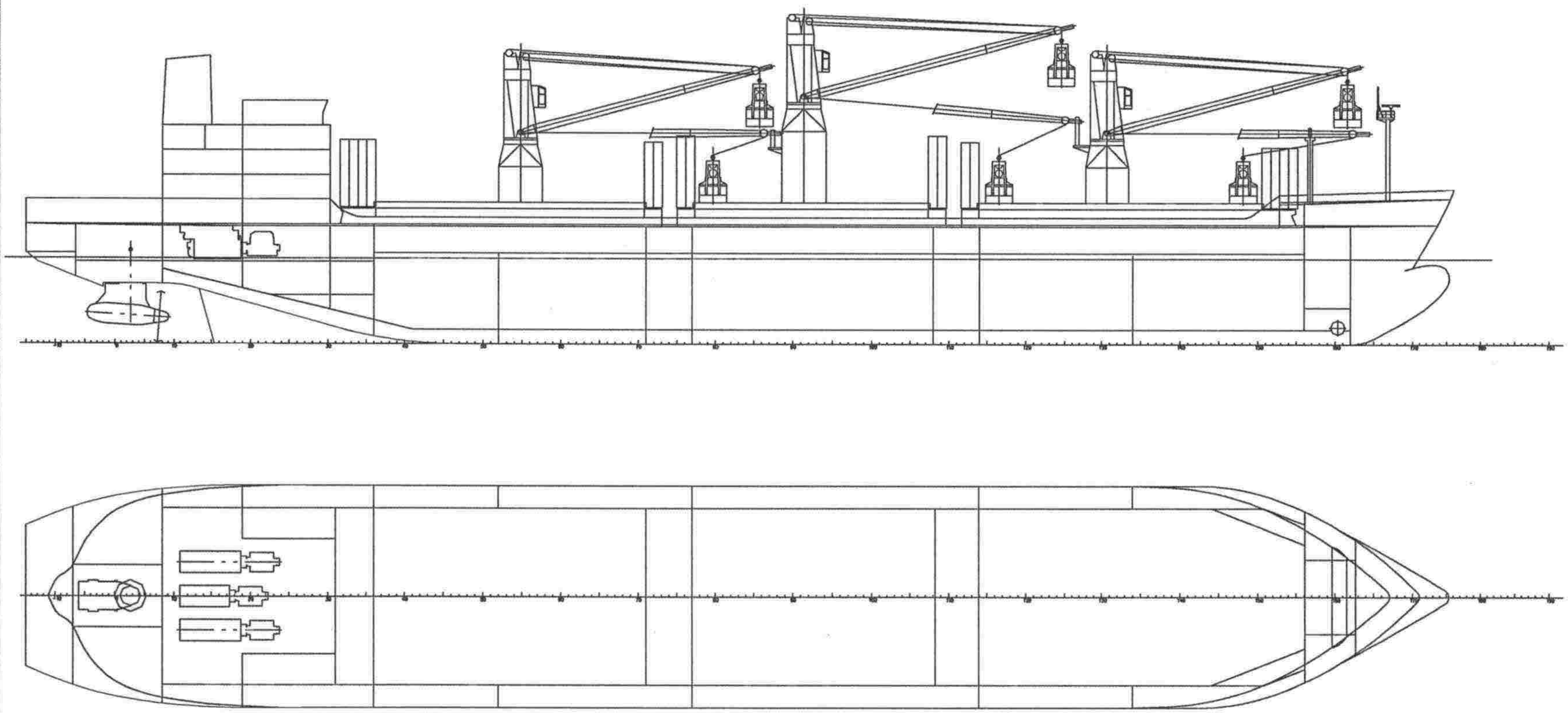
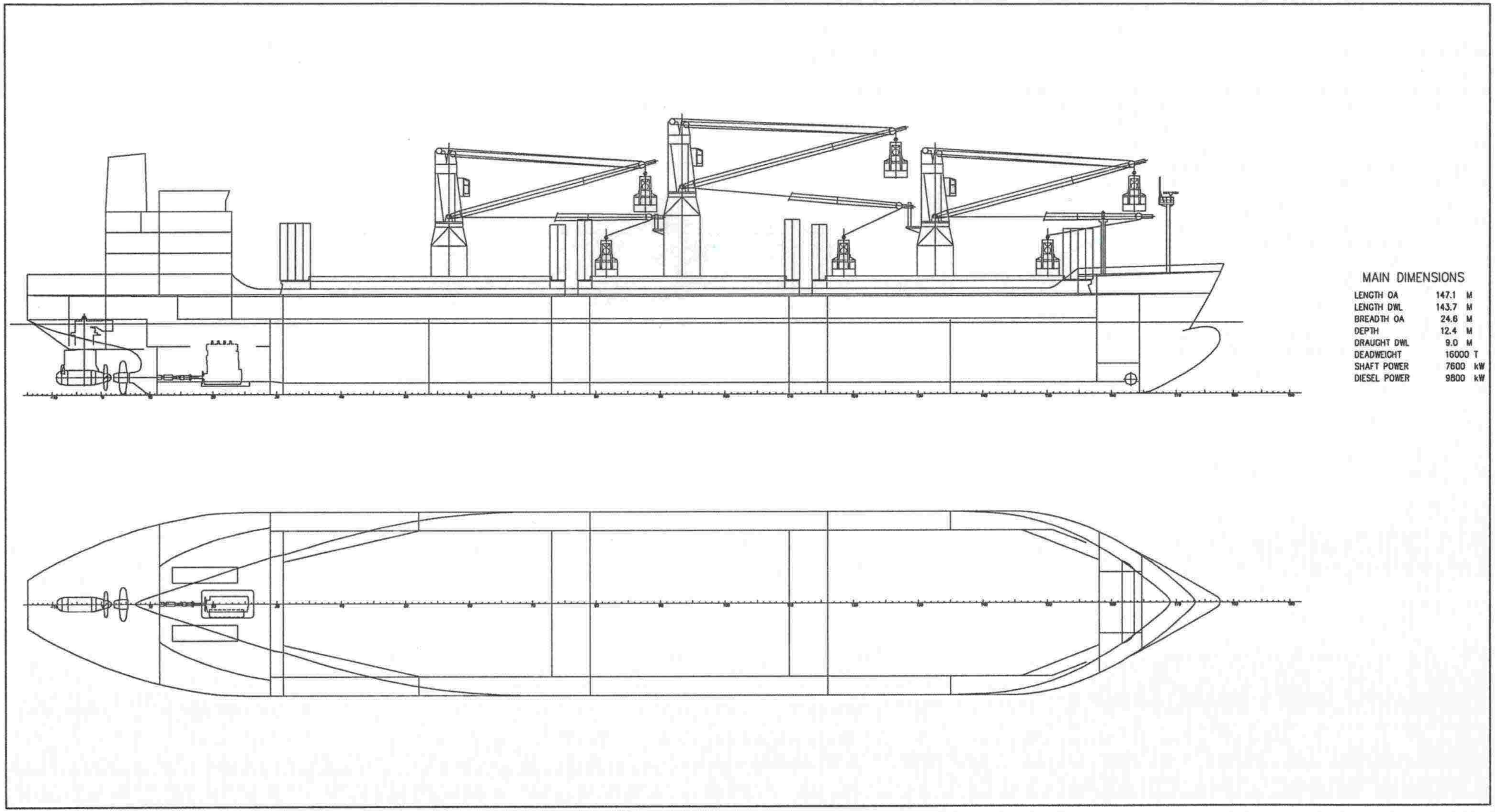


MAIN DIMENSIONS

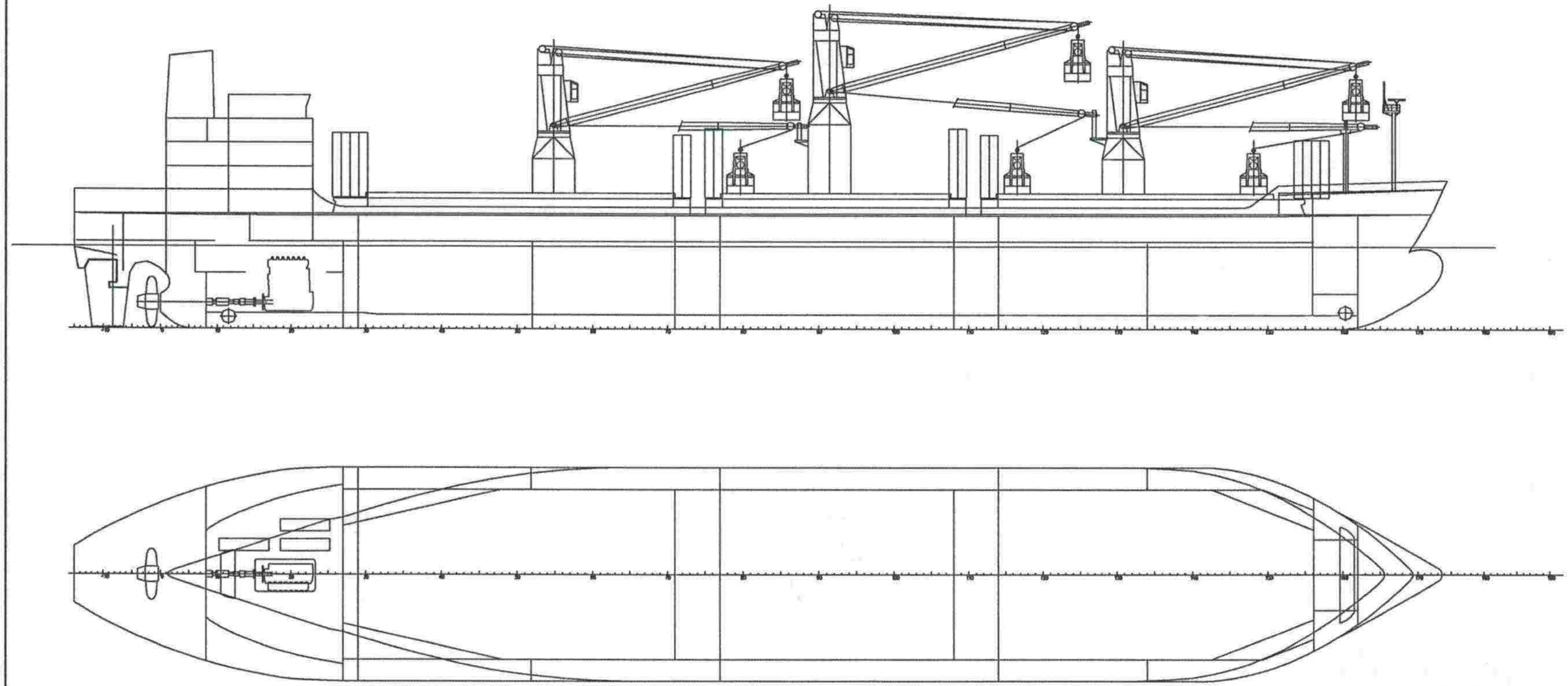
LENGTH OA	148.5 M
LENGTH DWL	144.0 M
BREADTH OA	23 M
DEPTH	12.4 M
DRAUGHT DWL	9.0 M
DEADWEIGHT	16000 T
SHAFT POWER	7600 KW
DIESEL POWER	11000 kW

SHIP VERSION C



APPENDIX A

SHIP VERSION O



MAIN DIMENSIONS

LENGTH OA	145.9 M
LENGTH DWL	142.2 M
BREADTH OA	23 M
DEPTH	12.4 M
DRAUGHT DWL	9.0 M
DEADWEIGHT	16000 T
SHAFT POWER	8300 KW
DIESEL POWER	11500 KW